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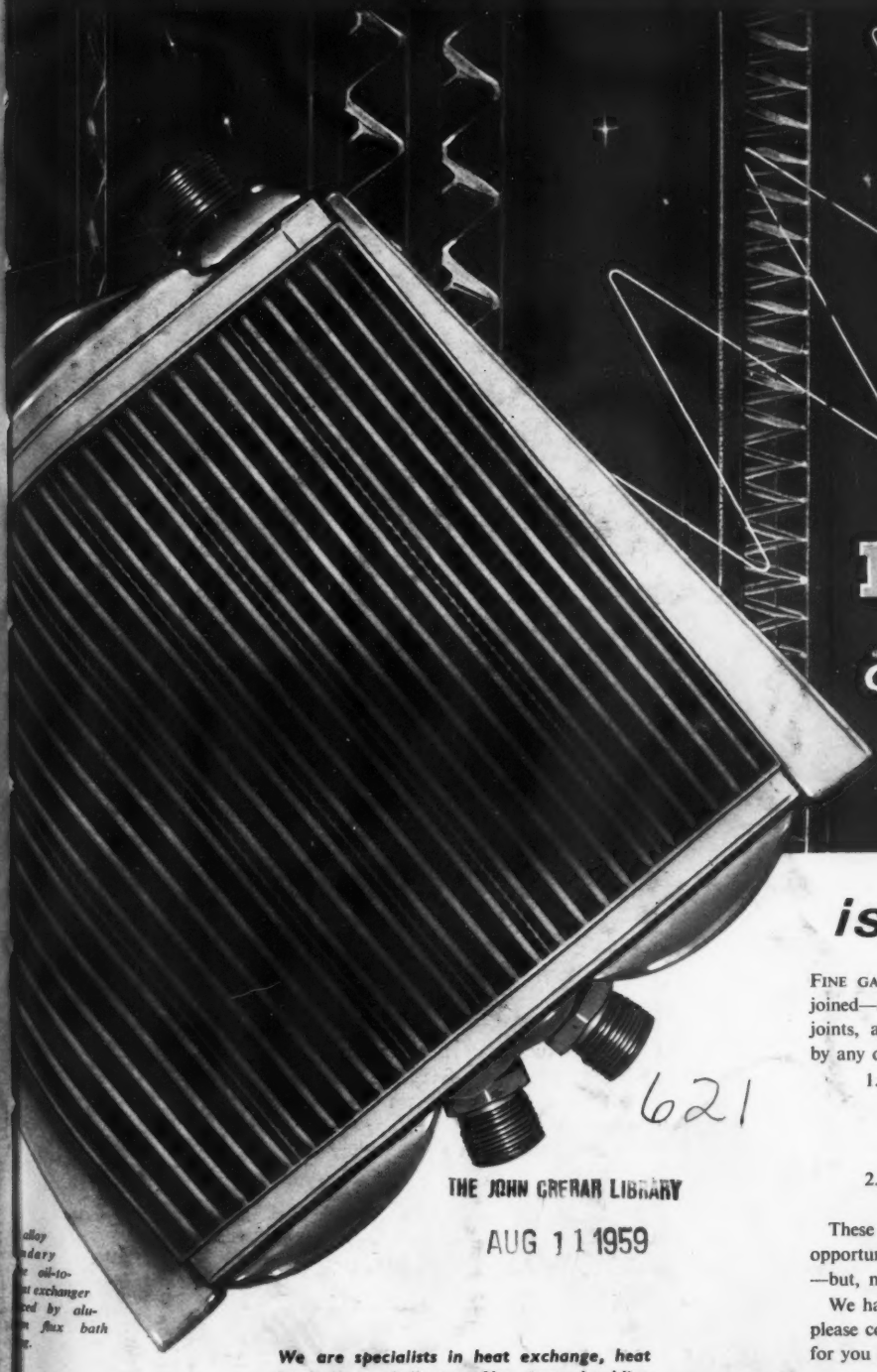

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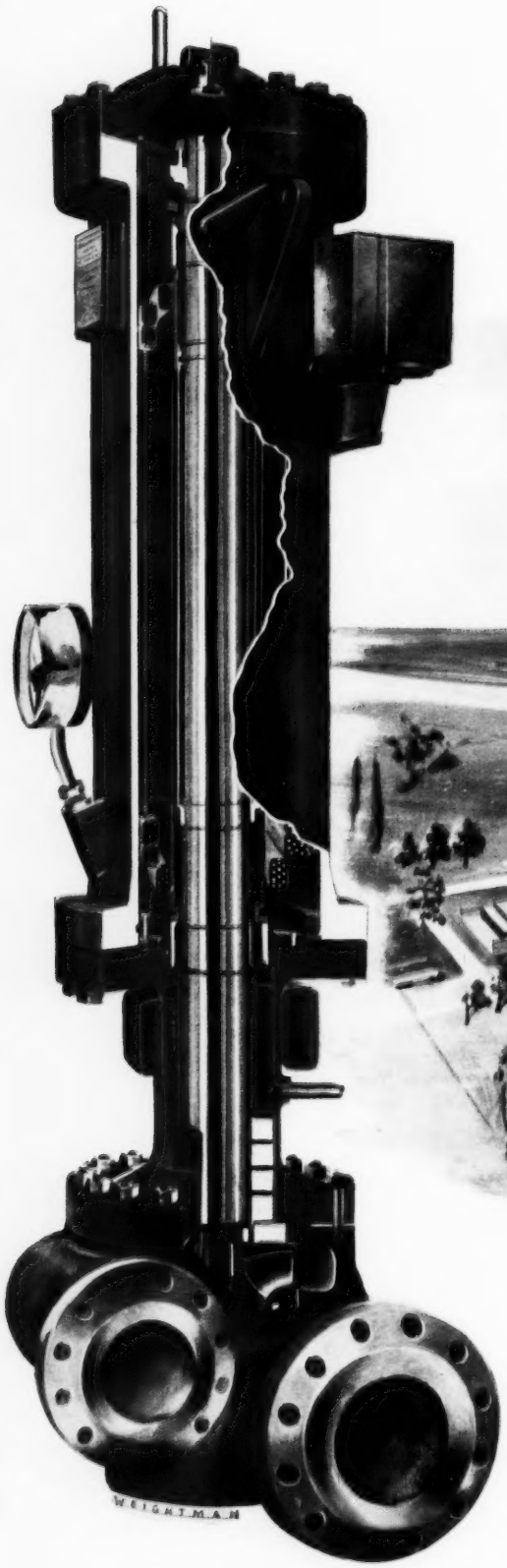

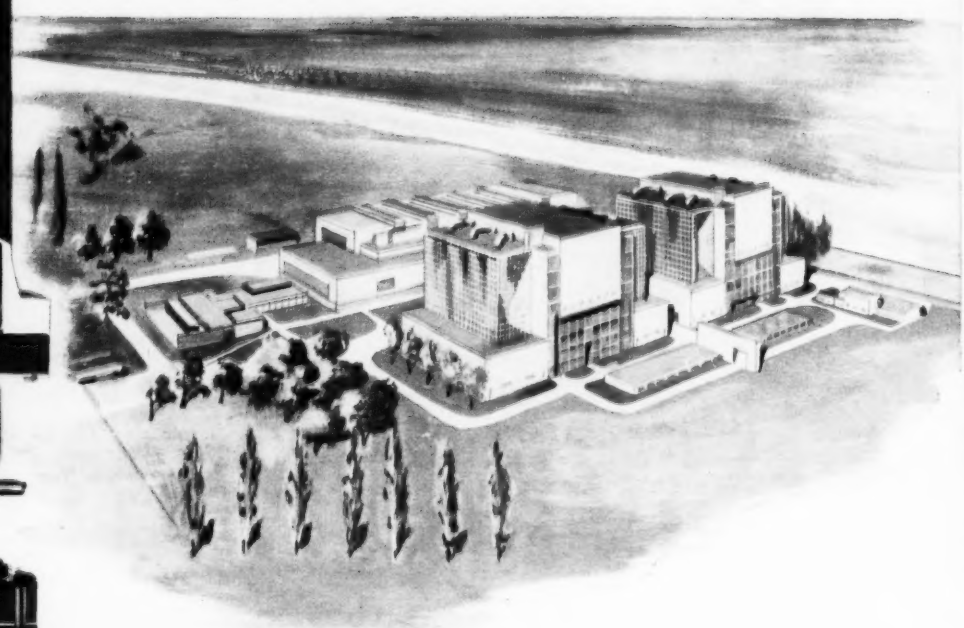

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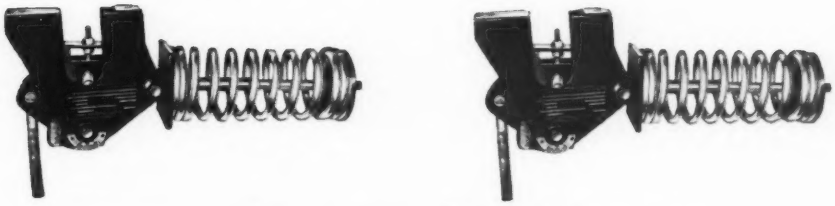

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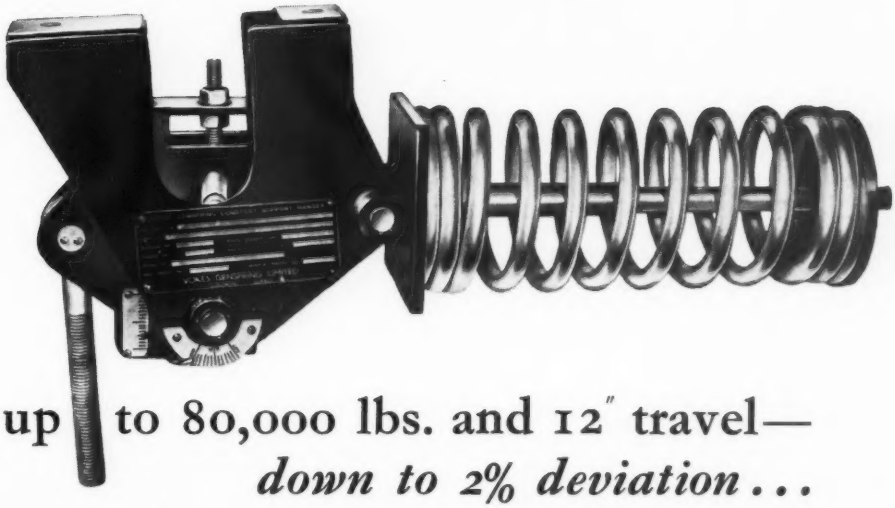

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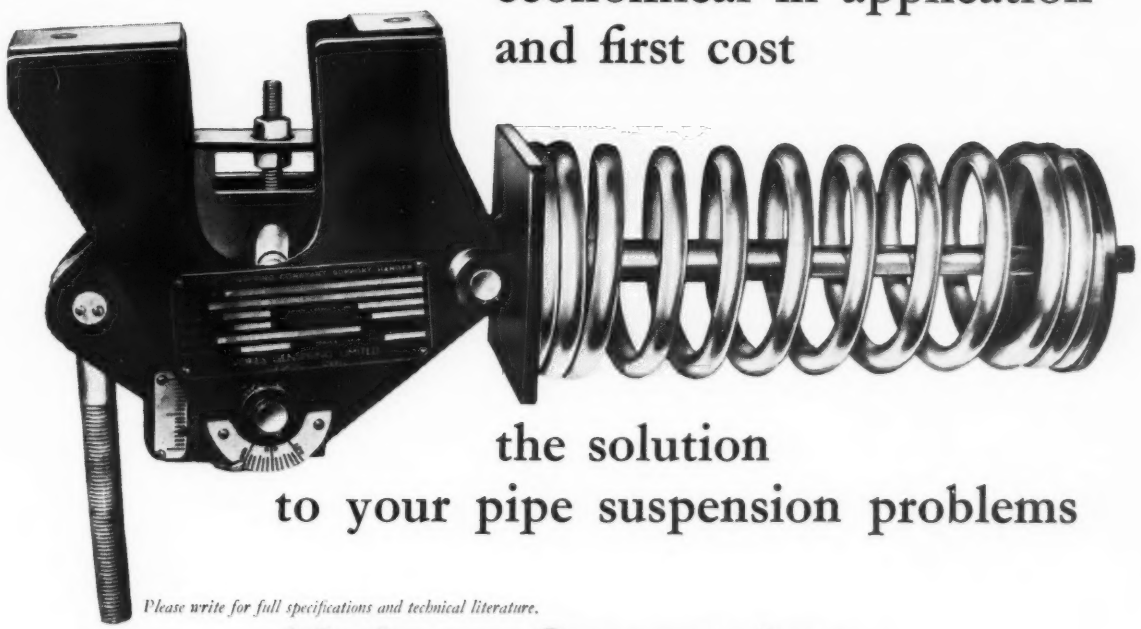

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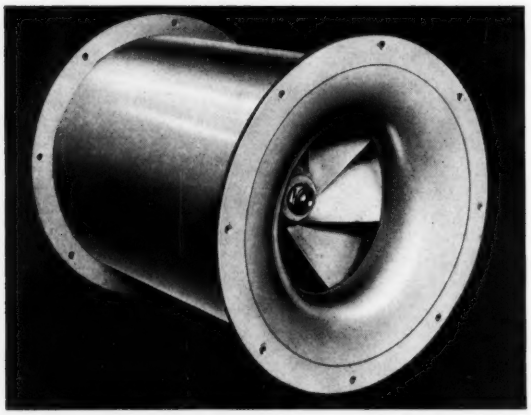

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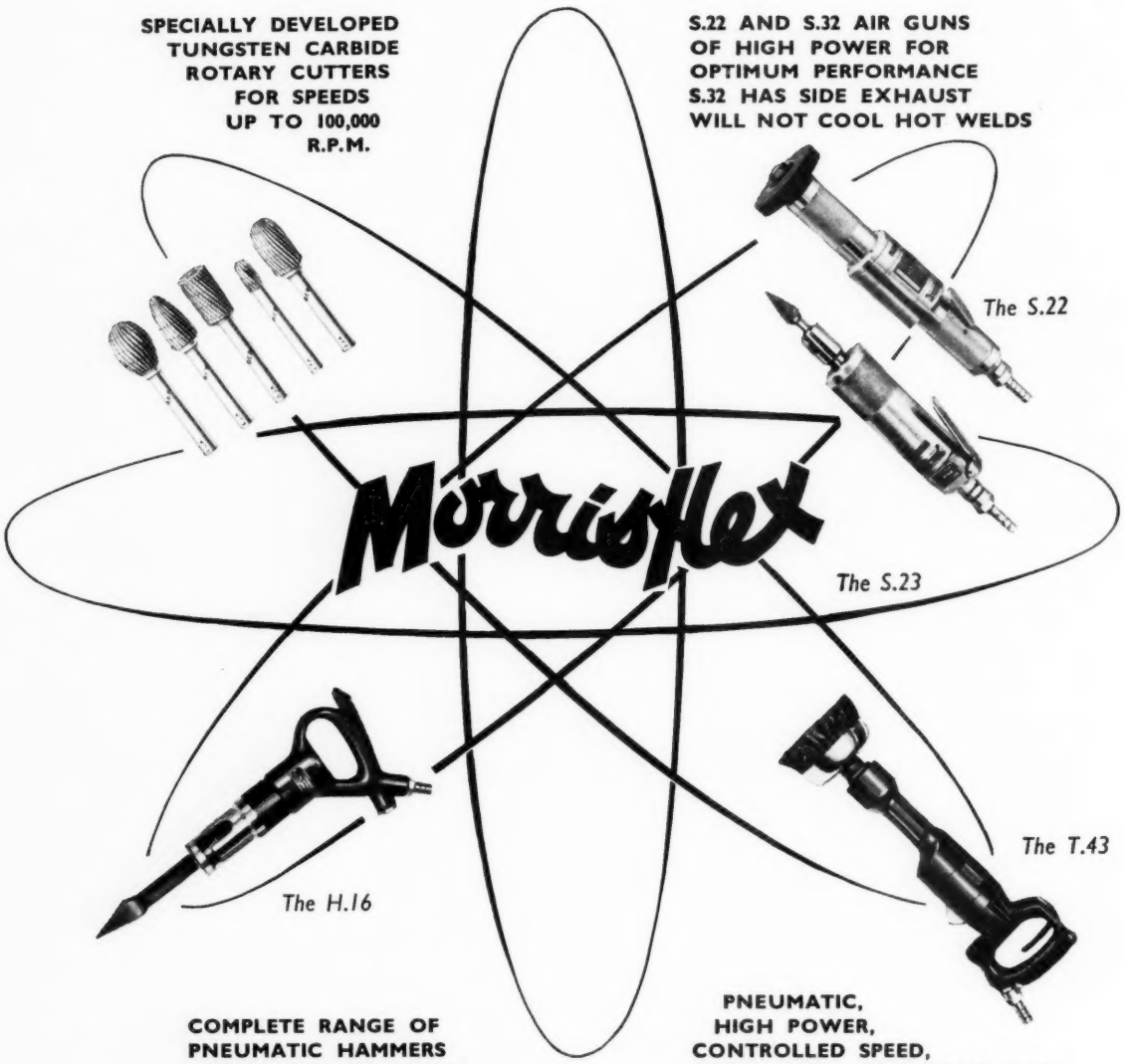

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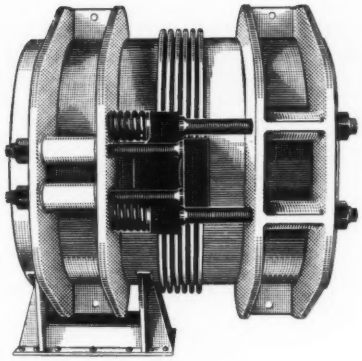

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NUCLEAR ENERGY ENGINEER

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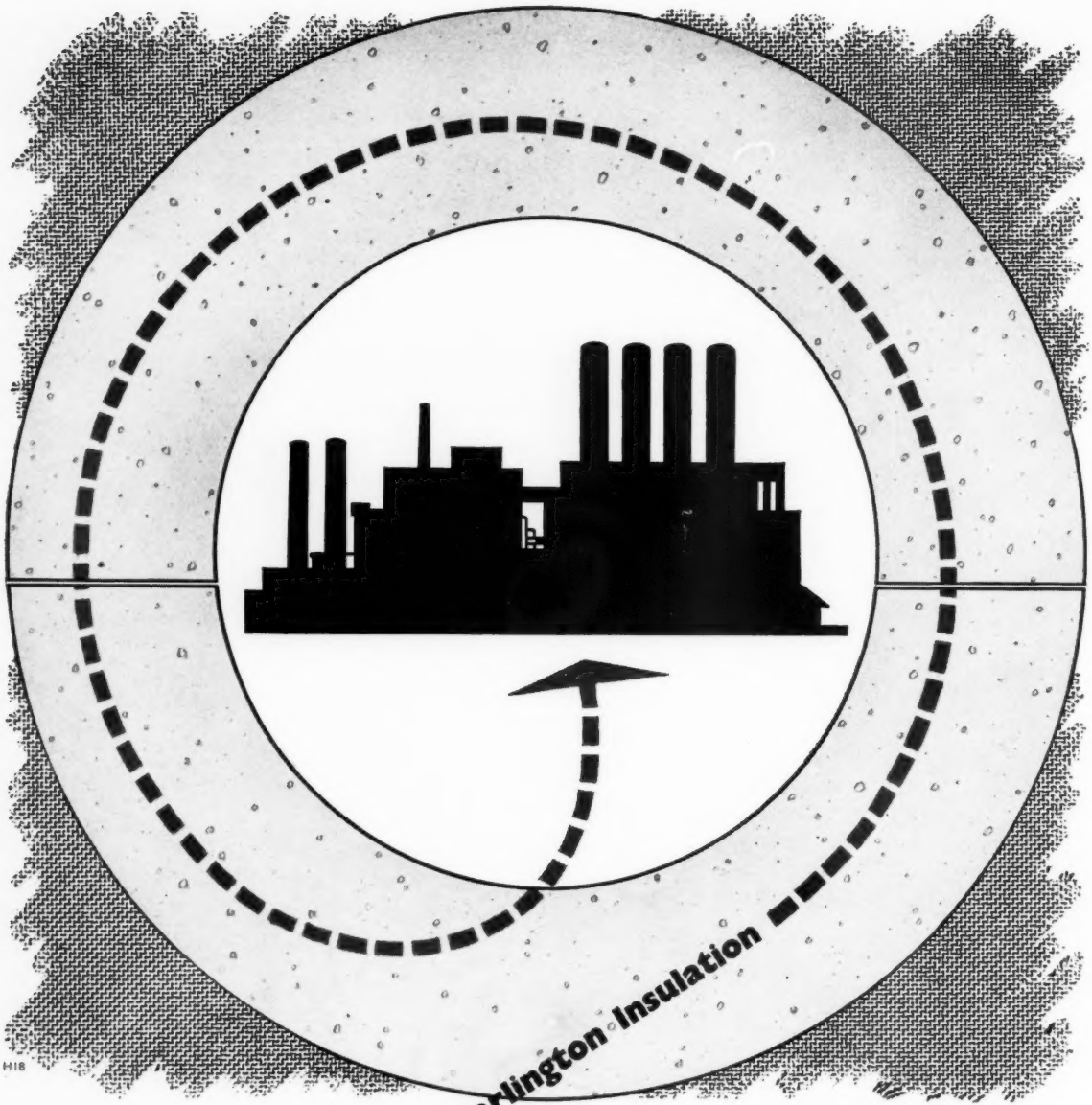

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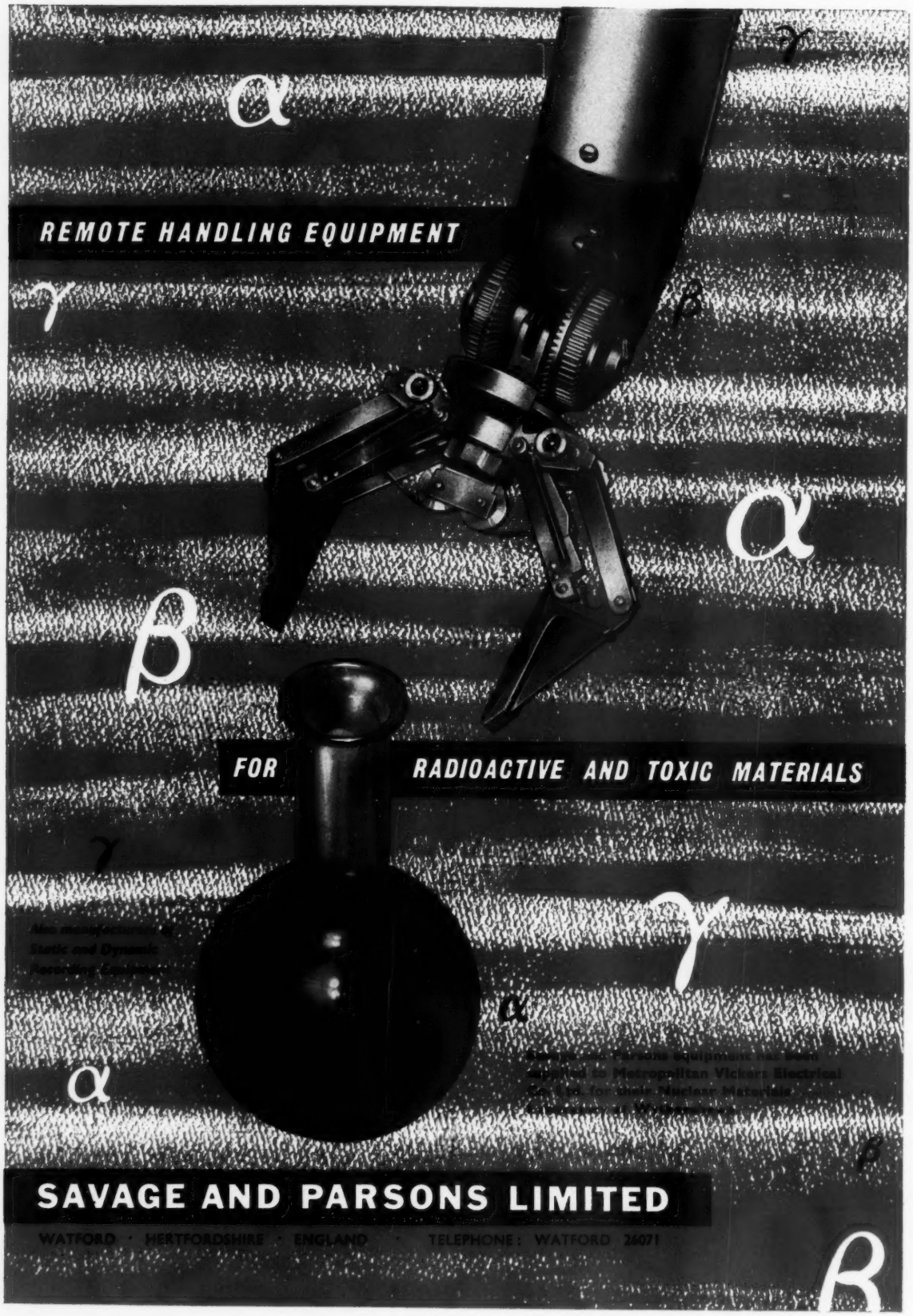
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Laboratory for Studying N-Materials

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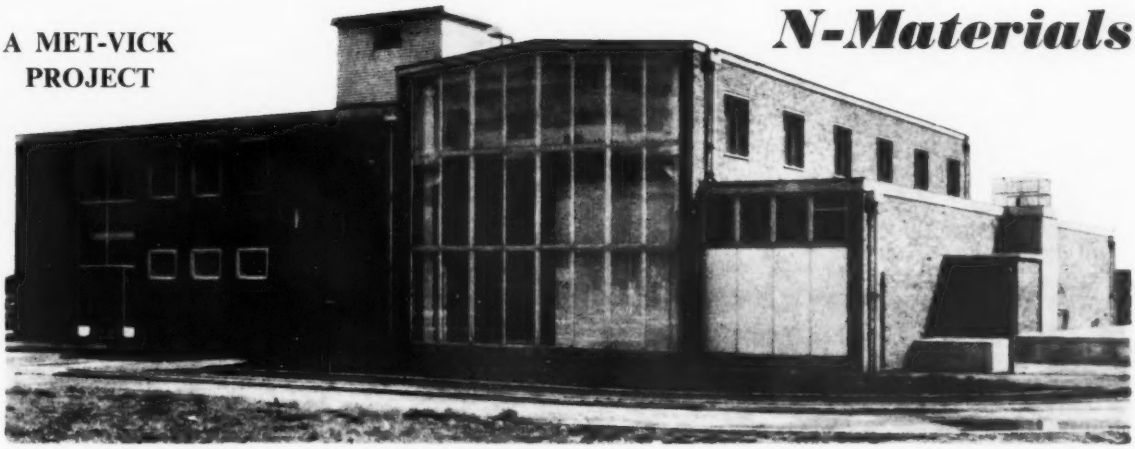


TO ascertain the effects of irradiation on materials used in a nuclear reactor, Metropolitan-Vickers Electrical Co., Ltd., have put into operation at their Wythenshawe works a specially designed nuclear metals laboratory. Equipped for the examination and testing of irradiated components and materials ranging up to a complete fuel element having an activity of the order of 10 kilo-curies, the £200,000 laboratory will primarily be engaged on work for the AEI-John Thompson Nuclear Energy Co., Ltd., and on work under contract for the UKAEA.

The main features of the laboratory are two large concrete caves and a train of five interconnected lead-walled cells. Ancillary to these are a decontamination area effluent treatment plant, ventilation and air filtration plant and health physics laboratory. There are also a general examination laboratory for examining low radioactive materials and a workshop.

The caves, which are used to receive large irradiated objects, such as test rigs or complete fuel elements, have 3 ft thick walls and internally they measure 8 ft × 6 ft × 11 ft high. The back of each cave can be rolled back on four roller bearing "skates" giving access to the inside. The inner side of the "doors" and of the walls of the caves are lined with tinned sheet steel painted with epoxy resin paint and when a "door" is closed an airtight seal is formed.

Manipulation by TV

Air pressure inside the caves is kept lower than that in the body of the laboratory so as to prevent airborne radioactive dust from escaping. Manipulative operations of objects inside the caves are carried out by remote control handling equipment. Television is installed to give operators of this equipment full two-dimensional view of the interior. Small lead-glass observation windows are provided for emergency use or in the event of failure of the TV system.

Special ports are fitted to allow radioactive fuel elements to be transferred from the "coffins," in which they are transported, to the interior of the caves. These ports are closed by thick lead doors when not in use.

One cave is fitted for the cutting up of fuel elements and contains a special diamond cutting machine, and a power-operated manipulator capable of lifting and moving objects up to 200 lb in weight. The cutting machine operates under water to prevent the spread of radioactivity and is so designed that it can cut fuel elements sectionally and lengthwise and can even cut a can without cutting the irradiated fuel inside. Both the cutting machine and manipulator were designed and built by Metropolitan-Vickers.

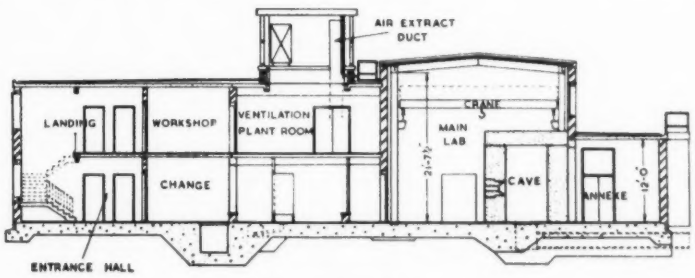
From Cave to Cell

In the other cave specimens can be examined visually, via television, and their dimensions measured accurately before dissection. Mechanical testing can also be carried out in this cave.

When this preliminary examination has been completed it may be necessary to carry out detailed metallographic examination on selected portions of the fuel element assemblies. This is carried out in the cells.

There are five cells, arranged in line and interconnecting. They are built on a concrete bench away from the wall thus enabling operations to be carried out from both sides of the line.

The cell walls are constructed of 6 in. thick lead slabs, with the roof in the form of a removable concrete



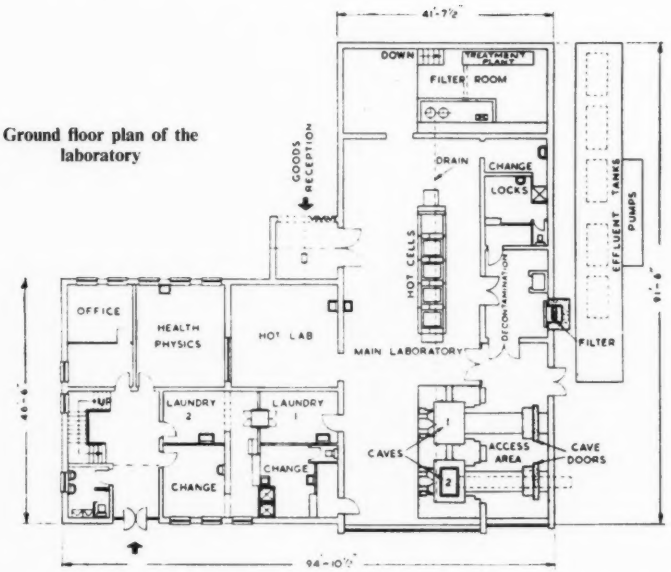
Cross-section of laboratory

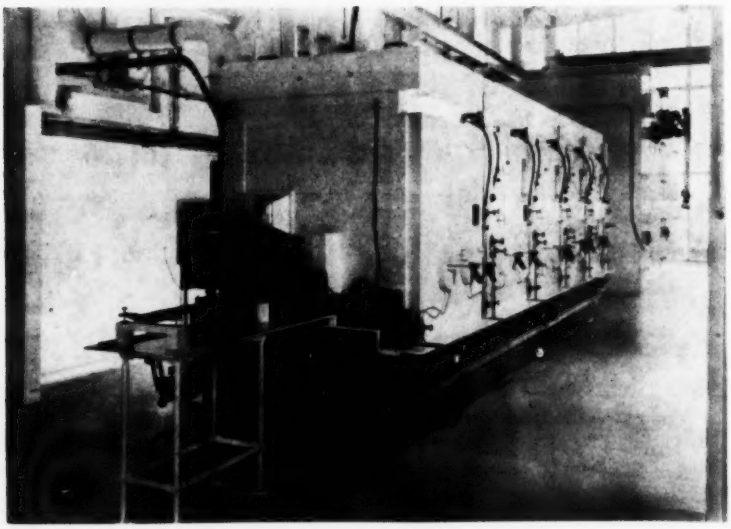
slab, and each cell has an inner container constructed of steel and Perspex making it practically airtight. This inner container is maintained at a slightly lower pressure than the laboratory by extracting air from the cell via a filter into the main air extraction system.

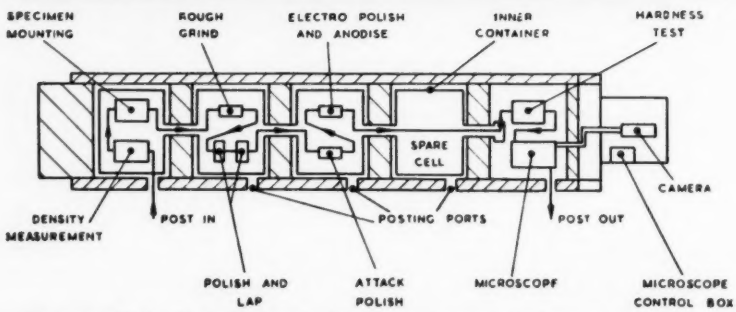
Lead-glass windows and spherically mounted handling tongs are provided on both faces of each cell, and remote controls for apparatus in the cells are brought through the walls where needed. All these controls are arranged so that they can be disconnected and the inner container lifted out as a whole when necessary for cleaning and decontaminating. Each cell has an entrance port with a sealed door, enabling objects to be put into and removed from the cells to and from closed containers, without causing any radioactive hazards. There are also the transfer ports from each cell to the next to allow objects to be passed from cell as required.

It is perhaps easier to visualize the scope of these cells from a description of the progress of a typical radioactive sample along the line. The sample may consist of a small section, say $\frac{1}{8}$ in. thick, of a uranium rod about 1 in. diameter, this rod forming the fuel in a particular fuel element which has been dissected in the large caves. It is transferred from the caves to the first cell in a small lead coffin which is run up on a stand to the entrance port of the first cell.

Ground floor plan of the laboratory







The train of cells. In top illustration the caves can be seen in background. (*Please note: photo is reverse view to plan*)

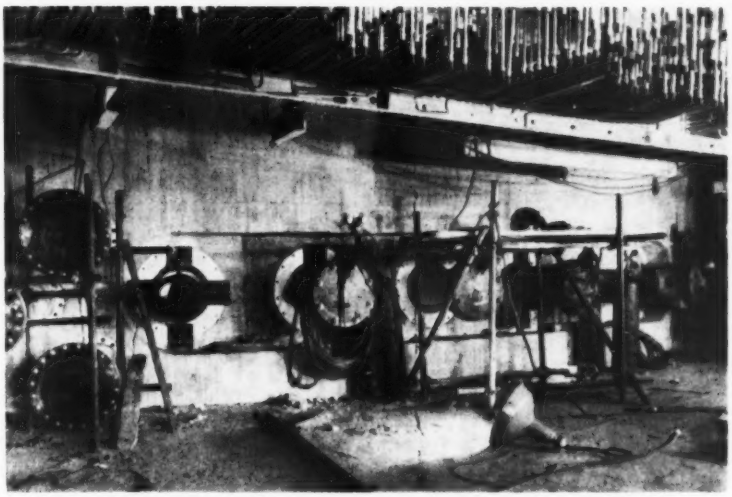
The port of the coffin and of the cell are opened and a transfer mechanism pushes the sample into the cell where it is deposited on a tray at the end of a movable arm. The ports are closed, the coffin is removed, and the arm moves down so that the sample can be lifted out of the tray by one of the handling tongs. In this cell is an Oertling balance, on which all weighing can be carried out by the addition and removal of riders which are remotely operated from outside the cell. In this way the specimen is weighed and its density determined. The specimen is then mounted in cold setting resin by means of an automatic mounting device in this cell.

Rough Polishing

The mounted specimen is put in the transfer tray and sent through the transfer port into the second cell where there are three standard automatic polishing machines. The first is equipped for rough grinding the surface of the specimen, and the second and third machines can be used with interchangeable polythene carborundum laps to polish and lap the specimen to a suitable finish.

(*Continued on page 406*)

DESIGN and working pressures of each of the reactor vessels for Berkeley nuclear power station are, respectively, 137 lb/sq.in. gauge and 125 lb/sq.in. gauge. Reactor gas inlet temperature will be 160°C. and outlet gas temperature 345°C. To ensure that the vessel is well able to meet these requirements it is tested to withstand pressures of up to 211 lb/sq.in. gauge and temperatures between 575°C. and 650°C. Photographs on this page illustrate the techniques and apparatus used in testing No. 1 reactor vessel which was recently accepted by Lloyd's Register of Shipping as being suitable on behalf of their clients, the Central Electricity Generating Board. Similar techniques will be used for testing No. 2 pressure vessel. Both vessels are constructed by John Thompson, Ltd., partners in the main contracting company.

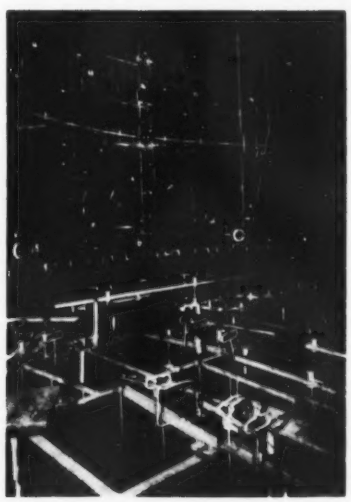


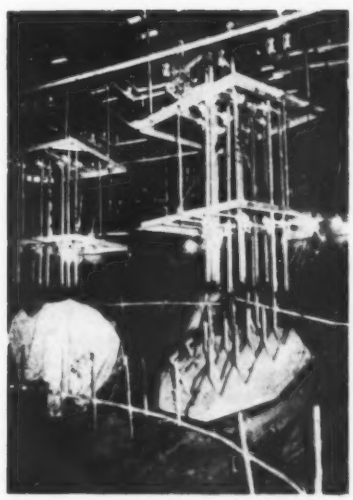
The pneumatic test on No. 1 reactor pressure vessel was completed in two days. Four Ingersoll Rand two-stage type compressors (*above*) were used in the test. Each had a working pressure of 200 lb/sq.in. gauge and output of 375 cu.ft/min. Compressed air passed from the compressors first into a Tilghman booster (seen in the background), where the pressure was increased from 100 lb/sq.in. gauge to 211 lb/sq.in. gauge, and then into the reactor vessel. To ensure the vessel was airtight, outer biological shielding tubes (*right*) were sealed

TESTING a pressure vessel

For the stress relieving operation, which took 14 days, the reactor vessel was completely insulated to ensure a minimum loss of heat and then subjected to temperatures in the region of 575-650 C. Over 300 thermocouple assemblies were used to ensure accurate temperature measurements. An engineer is seen in the picture below checking some of the assemblies

Heaters for stress relieving were fitted to the 165-ton diagrid and to the sides of the vessel (below). In this picture associated busbars can also be seen





The above illustration shows the bottom dome section of the vessel during its preparation for the stress relieving. Main busbar assemblies are shown in the course of erection

The Steam Cooled Reactor

by Norman Battle

Eight proposals for the nuclear propulsion of surface ships were brought forward at a recent presentation to the Admiralty Board and the Galbraith Committee, seven by industry and one by the UKAEA. The heavy water moderated, steam cooled reactor system described in this article was presented by Vickers Nuclear Engineering, a group of companies formed by Rolls Royce, Foster Wheeler and Vickers Armstrongs. The author of the article is senior designer of the Rolls Royce Advanced Nuclear Projects section.

VICKERS Nuclear Engineering made the choice of a heavy water moderated, steam cooled reactor system on the basis of the use of existing reactor technology so that prolonged testing and development would be unnecessary. Heat output of this reactor is 150 MW.

Heavy water was chosen as the moderator since it is the best moderator, and being a liquid presents few problems of storage on ship.

Reactor control through heavy water level changes by means of valves, without moving parts in the core, is also possible, and in a marine reactor which has to withstand accelerations due to ship's movement, and external shock, a system of control in which only fluids have to move, is obviously attractive. Problems of securing the moderator in place and of possible jamming of control rods, do not arise.

Why Steam

Steam was chosen as the heat transfer medium. It has a large background of practical experience; the reactor becomes a superheater which produces steam at conventional temperatures, which is the ultimate purpose of the plant; and it is possible by means of a thermocompressor to circulate steam in a circuit in which the only mechanical power required is supplied by a feed water pump.

The steam passes through the reactor in pressure tubes, and since this involves the repetition of small units, output can readily be scaled to suit a variety of requirements, and the moderator can be contained at low temperature and atmospheric pressure.

The fuel is uranium oxide in pellet form, in stainless steel cans. These materials do not react chemically with one another, or with water or steam.

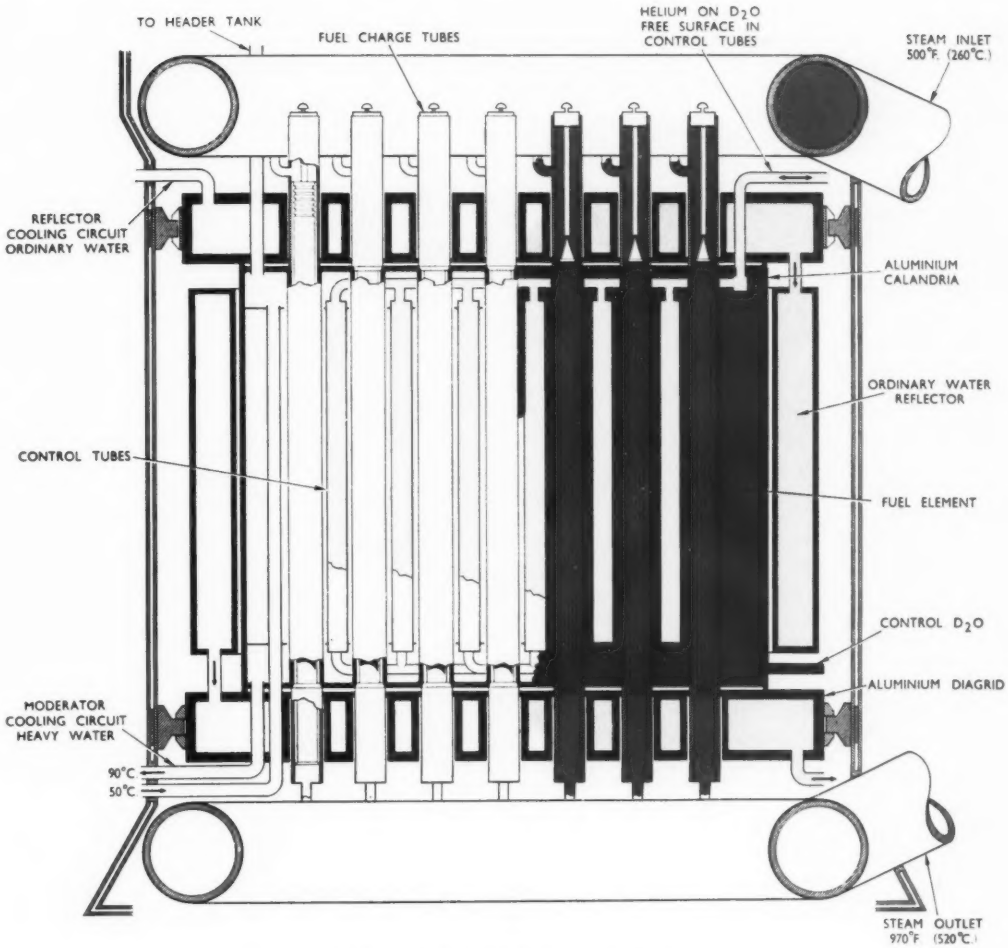
The core of the reactor consists of a 10 ft right cylindrical aluminium calandria tank through which pass 186 pairs of concentric tubes, each pair consisting of a thin stainless steel barrier tube which surrounds the fuel element clusters and carries the main steam coolant flow, and an outer aluminium alloy (3 per cent. magnesium) tube welded at both ends to the aluminium core tank. The annular insulating space between the tubes is filled with helium at a pressure equal to the steam pressure at outlet from the inner stainless steel tube.

Effective Containment

In this way, the 3.635 in. inside diameter aluminium tube which is in contact with the heavy water moderator in the core tank over its whole length, effectively contains the steam coolant pressure of 600 lb/sq.in. abs. at the mean moderator temperature of 160°F., while the 3.100 in. inside diameter .015 in. thick unstressed stainless steel barrier tube contains steam varying in temperature over its length from 500°F. to 970°F. The alloy proposed for the pressure tubes has a 0.1 per cent. proof stress of about 10 tons/sq.in., and though heavily irradiated, should have an indefinitely long life if the working stress is kept down to about 2 tons/sq.in. A tube wall thickness of .250 in. meets this case.

Inlet and outlet steam connectors are substantial austenitic stainless steel forgings screwed into the

(*Left*) **Cluster of fuel rods for the VNE reactor.** (*Right*) **Length of fuel rod showing helical spacing fin**



Section through the VNE steam cooled reactor

calandria tank, so that a conical metal to metal seal at moderator temperature prevents loss of helium from the insulating annulus.

Steam Flow Control

The top inlet steam connections are fitted with detachable seal plugs through which the fuel elements are inserted into the core. The bottom steam outlet connections contain adjustable gags for the regulation of steam flow to suit heat production in individual channels.

A separate pipe from each connection leads to ring header pipes situated at both inlet and outlet end of the reactor. Three layers of pipes accommodate the connections for 186 fuel channels and the positions chosen for the ring headers make adequate allowance for differential expansion between the steam pipes and the calandria tank which is relatively cold.

Reactor criticality control is achieved by moderator removal from 147 closed ended aluminium tubes disposed within the calandria tank between the fuel element channels, and connected in groups of three, so that rolling of the vessel in which the reactor is installed does not affect mean control moderator level across the reactor.

Fine Control

Fine control is proposed, by adjustment of moderator level in a limited number of tube groups, while an operating programme can specify maintenance of the remaining groups either full or empty, to give some flux flattening and cope with burn-up. About 40 per cent. of the total core moderator can be removed in this way so as to give adequate control.

Seven-Second Discharge

The 53 control tube groups are each connected to separate solenoid operated inlet and outlet valves. A small pump drawing on dump tanks situated in the main biological shielding below the reactor supplies a constant head at the inlet valves and also provides the head which closes 53 large flow area, main dump valves.

A solenoid operated valve is associated with each of seven restrictor-fed pressure lines to groups of eight dump valves, the solenoid valves being kept closed in the "current on" state, for "fail safe" operation. Thus, interruption of current to these solenoids releases servo pressure on the dump valves for reactor scram.

The control tubes, which can be emptied in this way in seven seconds, discharge approximately 40 per cent. of the core moderator to the dump tank. A cast aluminium alloy, light water cooled, hollow diagrid, is attached to each end of the calandria tank both by welding to the tank around its periphery, and at each end of the 186 fuel channel stand pipes by means of double ring nuts. These can be positioned to accommodate any lack of parallelism between the diagrids and the core tank.

Reflector Arrangements

The water content of the two diagrids completes the reflector arrangements at the top and bottom of the core. The side reflector system additional to 4 in. of heavy water in the core tank, consists of a further 10 in. of light water contained in a toroidal aluminium tank separate from, but surrounding the core tank, and supported on the outer edge of the lower diagrid.

Nineteen rod fuel element bundles approximately 11 ft long hang from the upper end of the barrier tubes at the top of each fuel channel, and are also attached to the seal plugs fitted into the stand pipes at the top face of the reactor so that fuel elements and seal plugs are fitted as one unit. The rods are fixed at their top ends relative to each other but are free axially at their lower ends.

Fuel Rod Fabrication

UO_2 in .500 in. diameter, .750 in. long sintered pellet form, clad with .010 in. thick austenitic steel (Jessop's R.20), forms the fuel rods, which are continuous through the core. The cladding is in the form of strip material turned up along two edges so that a helical spacing fin is formed when the strip is wrapped around a mandrel and twisted axially before undergoing a continuous automatic seam welding process. Adjacent rods have opposite hand fins so that good mixing of the steam coolant takes place through the channel. At both ends of the rods outside the 10 ft core region, porous alumina replaces uranium oxide to provide space for fission product gases, and keep the comparatively heavy section steel end spacer pieces clear of the core region.

A fuel enrichment of 1.7 per cent. gives an operational life of about 8,000 full power hours with full Xenon override. This represents a burn-up of 4,500 MW days/tonne. The reactor poisons out in this case at 11,000 full power hours. An enrichment of 2.2 per cent. makes a burn-up of 10,000 MW days/tonne possible and gives a lifetime with full override of 19,000 hours.

Fuel element maximum surface temperature is 680°C. and fuel centre temperature 1,700°C.

The stand pipe seal plug incorporates a deformable silver sealing sleeve, which undergoes a degree of extrusion between the seal plug and the bore of the standpipe, when it is inserted. It has been assumed that steam direct from the reactor will not be acceptable at the turbine stop valve for the first plant, and thus there will be primary and secondary steam circuits. With increased experience it should be possible to dispense with secondary steam generators and take reactor steam direct to the turbines.

Conventional Circuit

The secondary circuit is conventional, steam being supplied from a condensing evaporator and superheater at 800°F. and 420 lb/sq.in.

For the primary circuit, steam is raised initially in a boiler heated by steam from an auxiliary oil-fired boiler in the secondary circuit, and the reactor is warmed up at atmospheric pressure on a separate circuit consisting of this boiler and the emergency dump condenser.

The main primary steam circuit which then takes over consists of the condensing evaporator or secondary steam generator already mentioned, with a high pressure, once through steam generator, driving a thermo-compressor which circulates the steam through the reactor.

A high pressure feed pump draws the condensate from the secondary steam generator and delivers it at about 2,100 lb/sq.in. to the primary steam generator in which 75 per cent. of the 585 lb/sq.in., 970°F. superheated steam from the reactor outlet main by-passes the secondary steam generator to do the work of evaporation and convert all the feed water to steam at 1,800 lb/sq.in. and 650°F.

Dump to Sea

This steam is accelerated in the thermo-compressor nozzle so that at exit from the nozzle it entrains the low pressure saturated steam emerging from the primary steam generator. The combined flow is then decelerated in a diffuser to give the pressure rise to 615 lb/sq.in. necessary to recirculate it through the reactor.

The main part of the moderator is circulated through four heat exchangers connected in series, three of which are feed heaters in the secondary steam circuit. In the fourth, heat is rejected to sea-water via a fresh water intermediate circuit. A variable speed circulating pump is used so that moderator inlet and outlet temperatures can be maintained constant with variable reactor heat output.

With downward flow of the main moderator, natural circulation of the moderator within the control tubes is promoted and it appears that the heat produced there can be dissipated through the tube walls without excessive temperature rise.

A helium sweep of about 25 ft^3/min is provided through the dump tank and through the spill line to the weir tank. The helium flow containing free deuterium and oxygen continues through an asbestos platinum or palladium recombination unit to which additional oxygen is admitted to compensate for oxygen lost by oxidation of circuit components.

Vickers Nuclear Engineering Ltd

Vickers Nuclear Engineering Ltd. was formed by an association of Vickers Ltd., Rolls-Royce Ltd., and Foster Wheeler Ltd., specifically for studying the application of nuclear power to marine propulsion. Their first practical project has been the design and development of the prototype machinery for Britain's first nuclear powered submarine, *Dreadnought*, the reactor system for which is American. The VNE steam-cooled reactor system is entirely British, the actual reactor design and development having been undertaken by Rolls Royce. Vickers' contribution to the system has been on the marine engineering and shipbuilding side, and Foster Wheeler's on the steam generation and pressure system side

Recombined heavy water reaches an ion-exchange unit after a cooler, and is joined by a constant flow of D_2O from the weir tank. The combined flows are drawn through the ion exchange unit, by making a connection to the suction side of the main moderator circulating pump. Five gallons of D_2O per minute are treated.

Helium Flow

The helium flow continues via a diaphragm sealed gas holder which maintains constant pressure (approximately atmospheric) in the system and is protected against damage during accident conditions by quick acting valves. The dump and weir tanks accommodate the pressure rise and are themselves protected by a safety blow-off valve in the weir tank.

The insertion and withdrawal of the fuel element clusters from the reactor channels is accomplished by traversing gear, and limited fuel element containment equipment, which is part of the reactor top shield, so that a faulty fuel element can be removed from the reactor, with the vessel hove to, at sea.

Fuel Changing Facilities

This system also provides all the facilities required for charging and discharging fuel elements from the reactor when extensive fuel changing is required, up to the point where spent elements are ready for insertion in individual coffins for removal from the vessel.

The charge machine consists of an enclosing pressure vessel containing a 1 ft thick lead container mounted on roller bearings which can be rotated to bring any of its four compartments over any selected stand pipe access tube.

Universal Alignment

The machine is fixed eccentrically to a turntable which is eccentrically mounted within a larger turntable. In this way, the access tube which depends from the machine, through the inner turntable, can be aligned with any of the stand pipes. It is equipped with a magnetic search facility to assist accurate alignment and is telescopic so that a seal can be made with the outside diameter of the stand pipe, before the seal plug and attached fuel element, is withdrawn from the fuel channel. This operation is only undertaken with the reactor shut down and at low steam pressure.

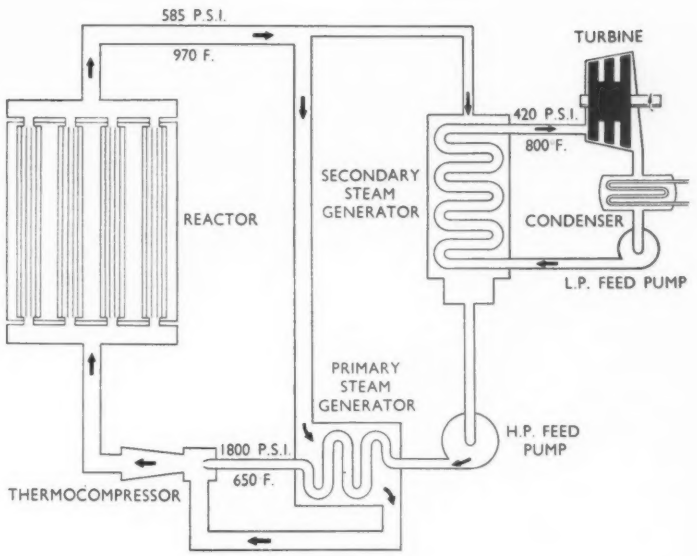


Diagram to illustrate reactor circuit

The two charge machine turntables, of steel and water construction, form the top biological reactor shield.

The side biological shield is also of steel and water construction. It is cylindrical in form, the reactor core supports being attached to the wall of the inner shell. A total shield thickness of 4 ft 6 in. is found to be necessary, of which 25 in. are of steel, and 29 in. are of water, including the water which forms part of the core reflector. The surface dose rate is approximately 1 rem/hr at full power.

Concrete Base

The bottom shield is of steel plate and girder construction 3 ft thick, filled with concrete, which is thus a good load-bearing structure for the reactor unit and the side and top shield.

The primary and secondary steam generators, feed pumps and all associated steam circuit components are grouped around the reactor and supported on the bottom shield structure, which is made of sufficient diameter for this purpose. A containment shell 46 ft in diameter, 1½ in. thick, with a domed top is attached to the circumference of this platform, and completely encloses the reactor unit and charge machine, all the primary circuit steam plant, and the secondary steam generators. Its overall height is 49 ft. The feed pump driving turbines are situated outside this containment, their drive shafts passing through it by means of special seals. The containment is designed to withstand an internal pressure of 120 lb/sq.in. gauge, which could arise as a result of the assumed maximum credible accident, which is the breakage of a 16 in. steam pipe in the primary circuit to the reactor inlet header.

The total weight of the reactor plant including the containment is 2,100 tons. This figure does not include the vessel's propulsion machinery or any of the secondary steam circuit components other than the secondary steam generators.

A scaled down 60 MW plant which could provide 20,000 s.h.p. would weigh about 1,200 tons, and have a diameter over the containment of 32 ft.

The Economics

Fuel investment would be 4.8 tonnes of uranium, and a U-235 enrichment of 2.5 per cent. would give a 10,000 MWD/tonne burn-up. This represents 800 full power days.

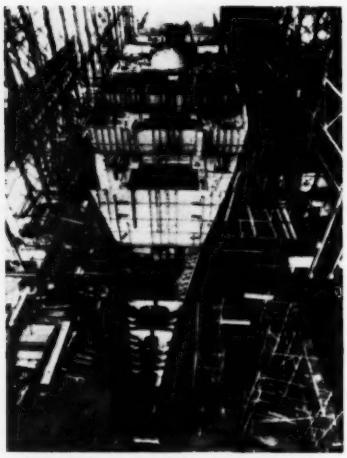
Estimates have been made which indicate that the capital cost of a developed plant plus the cost of fuel, for a period of 16 years, is not markedly different from that for an oil-fired installation. This assumes English oil prices at 153*s*. 6*d*. per ton.

N.S. *Savannah*

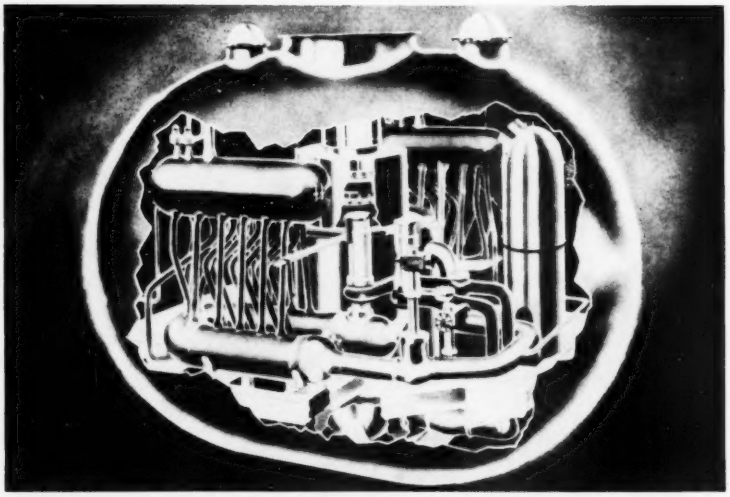
Launching of the world's first nuclear powered passenger cargo ship took place on July 21st at Camden, New Jersey. Sea trials of the ship are expected to begin early next year. The ship's pressurized water reactor was developed and fabricated by Babcock and Wilcox, with the De Laval Steam Turbine Company as major sub-contractors. There is space in this issue only for important data. A full account of the reactor and the physics involved will appear next month.

MAIN FEATURES

Length	587 ft
Beam	78 ft
Displacement	21,800 tons
Cruising speed	21 knots
Power	20,000 s.h.p.
Minimum cruising range without refuelling	350,000 miles
Passenger capacity	60
Cargo capacity	10,000 tons
Propulsion unit	74 MW pressurized water reactor
Fuel	UO_2 (4 per cent. enrichment)



Bow-to-stern view of the *Savannah* in the building yard at Camden, New Jersey. The keel was laid on May 22nd, 1958, by Mrs. Richard M. Dixon, wife of the vice-president. The reactor is expected to receive its first fuel loading early next year. Extensive trials will follow



Artist's impression of the reactor plant of the *Savannah* within its containment vessel. The plant includes in addition to the reactor itself, the cooling system, steam generators, pressurizer, and intermediate cooling, purification, control and instrumentation systems. The reactor plant is situated midships (*above*)

PRINCIPAL PLANT PERFORMANCE

Operating Condition	*Normal power*	*Maximum power*
Shaft power, s.h.p.	20,000	22,000
Propeller speed, rev/min	107	110
Turbine inlet pressure, lb/sq.in. abs.	470	450
Main condenser pressure, in. Hg abs.	1.5	1.5
Boiler drum pressure, lb/sq.in. abs.	490	474
Feedwater temperature, °F.	347	343
Total electrical load, kW	1,900	1,900
Total steam consumption, lb/hr	242,000	261,460
Reactor heat output, MW	63.5	69.0
Engineering Characteristics		
Primary loop pressure, lb/sq.in. abs.	1,750	1,750
Primary loop pressure drop, lb/sq.in.	69.5	69.5
Primary loop flow, lb/hr	8m.	8m.
Primary loop temperature rise, °F.	22.8	24.8
Primary loop mean temperature, °F.	508	508
Blowdown, lb/hr	2,400	2,600

Reactor Design and Performance Characteristics

Core Dimensions

Core overall length	90.24 in.
Active fuel length	66 in.
Equivalent core diameter	62.06 in.

Fuel Element Data

Fuel	UO_2
Cladding	Boron stainless steel
Ferrules	Stainless steel
Springs	Inconel-X
Can	Stainless steel
Straps	Stainless steel
Fuel pellet diameter	0.4245 in. (nominal)
Cladding outside diameter	0.500 in. (nominal)
Cladding thickness	0.035 in. (nominal)
Fuel rod spacing (square lattice)	0.663 in. (nominal)
Fuel rods per element	164
Ferrule outside diameter	0.4375 in. (nominal)
Ferrule inside diameter	0.3975 in. (nominal)
Length of ferrule	1.0 in.
Fuel elements in core	32
Fuel element can thickness (second pass)	0.109 in.
,, ,, ,, ,, (third pass)	0.094 in.
Heat transfer area	3,778 ft²

Thermal and Hydraulic Data

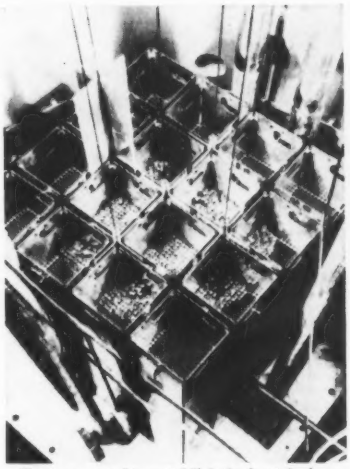
Reactor design power	74 MW
Reactor maximum operating power	69 MW
Reactor normal operating power	63.5 MW
Design pressure	2,000 lb/sq.in. abs.
Operating pressure	1,750 lb/sq.in. abs.
Total reactor flow rate	8.0×10^6 lb/hr
Velocity (average, second pass)	9.29 ft/sec
Velocity (average, third pass)	8.40 ft/sec
Per cent. leakage flow (second pass)	5 per cent.
Per cent. leakage flow (third pass)	10 per cent.
Per cent. total leakage flow	15 per cent.
Number of passes within reactor vessel	3
Bulk coolant inlet temperature at design power	494.7°F.
Bulk coolant outlet temperature at design power	521.3°F.
Average coolant temperature at design power (second pass)	499°F.
Average coolant temperature at design power (third pass)	512°F.
Core average coolant temperature at design power	508°F.

	Nominal channel (third pass)*	*Hot channel with flux peaking (third pass)*
Maximum coolant temperature, °F.	536	543
Maximum surface temperature, °F.	610	624
Maximum fuel temperature, °F.	3660	4434
Power to start local boiling, per cent. of design power	113 per cent.	91 per cent.
Power to start net boiling	285 per cent.	233 per cent.

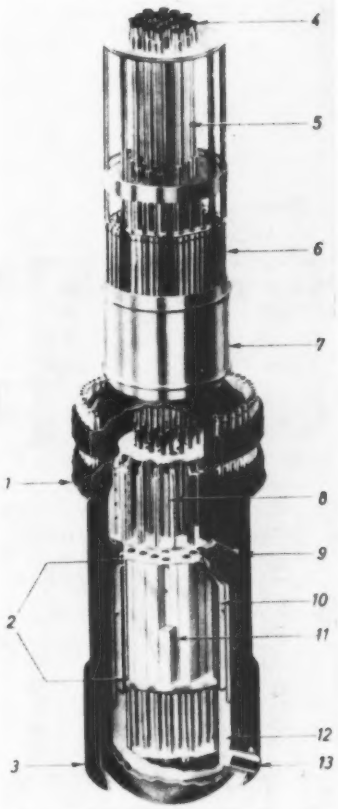
Nuclear Data

Metal/H_2O ratio	0.76
Volume fractions—	
Water	.5676
Control rods	.0397
Helium gap	.0064
Fuel	.2455
Stainless steel	.1408
Typical inventory and fuel burnup data for 52,000 MWD core life—	
Initial enrichment (wt. per cent.)	4.7 per cent.
Initial U-235 loading	331.4 kg
Initial U-238 loading	6,734 kg
Average burnup	7,360 MWD/ton
Final enrichment (wt. per cent.)	3.9 per cent.
Final U-235 loading	272.9 kg
U-235 consumed	58.4 kg
Final Pu-239 loading	17.4 kg
Final total Pu loading	19.6 kg
Per cent. metal atom burnup	1.2 per cent.
Average thermal neutron flux	7.5×10^{12}

*The nominal channel is assumed to be located in the region of maximum flux but does not include the effect of manufacturing tolerances.



Test core used to establish the best design for use in the *Savannah* reactor



General arrangement of the *Savannah* reactor

Key:—1 Reactor pressure vessel flange; 2 Effective core height; 3 Pressure vessel support skirt; 4 Control rod electric motor drives; 5 Emergency hydraulic control rod drive cylinders; 6 Electric drive lead-screw section; 7 Enclosure round control rod gland seals; 8 Cruciform boron-steel control rod; 9 Water outlet; 10 Internal thermal shields; 11 Rectangular cans containing fuel rods; 12 Flow baffle; 13 Water inlet

HYDROCARBONS in Power Reactor Plants

I.—The Organic Moderated Reactor Experiment

Hydrocarbons have great possibilities as both coolant and moderator in nuclear reactors, also as coolant only. In view of recent industrial announcements relating to the design, developments and construction of organic cooled-moderated reactors—the English Electric-Atomics International agreement on the exchange of OMR data, Hawker Siddeley's OMR ship propulsion unit, official sanction of the Piqua OMR power plant, and the Atomic Energy of Canada, Ltd. order for an organic cooled, heavy water moderated reactor—we are running a series of articles to acquaint readers with experiments and studies associated with this particular reactor concept.

THE technical and economic feasibility of using hydrocarbons as a reactor coolant and moderator has been demonstrated by the successful operation of the Organic Moderated Reactor Experiment (OMRE) at the National Reactor Testing Station, Idaho Falls. Operated on behalf of the U.S. Atomic Energy Commission by Atomics International, a division of North American Aviation, Inc., this experiment was established in 1957 and the reactor has been in service 85 per cent. of the time since it went critical in September of that year.

The primary purpose of the experiment has been to study the radiation and thermal stability of the organic materials used and the physical property changes of these materials under actual reactor operating conditions. Investigation of the performance of various types of fuel elements and of various reactor and process system components has also been made. A study of the general operating characteristics of the reactor has been conducted, too.

Attractive Properties

The most important properties of organic moderator-coolants which make their use in either land-based or mobile power plants attractive are as follows:—

1. Low volatility, which permits low working pressures and the use of low pressure equipment;

2. Negligible corrosion with standard materials of construction, which eliminates the need for using stainless steel and special alloys;

3. Low activation upon exposure to neutrons, which permits a minimum of shielding and therefore easy access to the reactor system for maintenance purposes; and

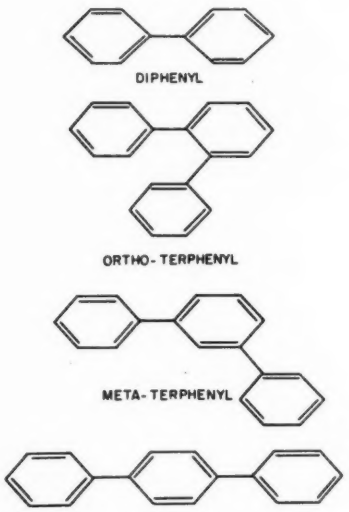
4. Very slow action reaction with uranium at high temperatures, thus eliminating the hazard of chemical energy release in the case of fuel element failure.

Early Tests

The evaluation of organic materials for use as moderators and coolants was mainly concentrated on an investigation of the stability of various commercially available hydrocarbons exposed to high radiation fluxes at elevated temperatures. The initial tests were carried out in small heated capsules exposed to radiation by high energy electrons from particle accelerators, and by neutrons and gamma rays from nuclear reactors. These tests pointed out the outstanding stability of diphenyl and the terphenyls, and of some of their derivatives and mixtures of these.

Further tests were carried out in circulating hydrocarbon loops in various reactors. Results from these in-pile tests confirmed the data obtained from the capsule experiments. In addition they showed no evidence of any tendency on the part of the decomposition products so formed to separate from the bulk of the coolant and deposit on either hot or cold heat transfer surfaces.

Diphenyl and the terphenyls are derivatives of benzene consisting of two and three aromatic rings respectively linked together by means of



Chemical formulae of diphenyl and the terphenyls

covalent bonds. High temperature irradiation of these compounds, known as polyphenyls, results in the formation of multi-ring high boiling compounds with simultaneous release of hydrogen, methane and small amounts of other light hydrocarbons. Table I shows some experimentally measured gas and high boiler residue formation rates for polyphenyls at a temperature of 750°C. and the consequent calculated formation rates which could be expected to prevail in power reactors.

Santowax OM Used

Originally the OMRE was designed to use diphenyl as coolant, reflector and moderator. During the construction of the experiment, however, a considerable amount of information on the physical properties and behaviour of the terphenyls was obtained. It was decided, therefore, to use a commercial mixture of polyphenyls having a much lower vapour pressure than diphenyl. This mixture consists mainly of ortho- and meta-terphenyl, with small amounts of

Table I—Radiolytic Decomposition Rates of the Polyphenyls

	Molecules formed	Decomposition products formed	Decomposition products formed	Coolant make-up cost[3]
	100 ev absorbed	kWh absorbed	Thermal MWn of reactor operation[1]	
Gas formation	0.005–0.012	42–100 cm³ STP	0.074–0.178 ft³ STP	0.75–1.80 mils/elec. kWh
High boiler residue formation ..	0.05–0.12	8.5–21 gm[2]	0.94–2.25 lb	

[1] Based on 5 per cent. energy absorption in hydrocarbon.
[2] Based on an average high boiler residue molecular weight of 458 (hexaphenyl).
[3] Based on a coolant cost of 20 cents/lb and a 25 per cent. conversion efficiency from thermal into electrical energy.

diphenyl and para-terphenyl. It is commonly known as Santowax OM. Its composition and physical properties are shown in Table II.

The physical properties shown in that table are for unirradiated material only. Changes in density, viscosity, vapour pressure and other physical properties occur as the material is irradiated.

OMRE Equipment

The reactor vessel in the Organic Moderator Reactor Experiment is a mild steel ($\frac{1}{2}$ per cent. molybdenum-1 per cent. chromium) pressure tank, $4\frac{1}{2}$ ft in internal diameter, 28 ft high and with a 1 in. thick wall. The core is located in the lower part of the vessel. Fuel is UO_2 made up into stainless steel sandwich fuel plates, 16 plates being made up into a fuel element.

Initial fuel loading consisted of 31 fuel elements containing 25.5 kg of U-235.

The reactor is pressurized with nitrogen, which provides an inert atmosphere above the reactor pool and maintains a pressure of 200 lb/sq.in. gauge on the system. Since small quantities of hydrogen and other light hydrocarbon gases are formed as the coolant is damaged a small nitrogen purge over the surface of the reactor pool is used to prevent build-up of these gases. After being scrubbed of organic vapours, the off-gas purge stream is directed through a gas chromatograph and then to the atmosphere through an exhaust stack.

As the coolant has a relatively large volume change with temperature an expansion tank is provided to allow operation over a wide range of temperatures without adjustment of the coolant inventory.

The reactor coolant is circulated at a rate of 9,200 gal/min (2,090 m³/hr) by use of two refinery-type, hot-oil centrifugal pumps operating in parallel. The heat which is generated in the reactor is dissipated to the atmosphere in an airblast heat exchanger. Constant-speed, variable-pitch fans and air-operated louvres control the heat injection rate. An auxiliary 100 kW heat sink is provided for the removal of afterglow heat when the main coolant system is inoperative.

A simple, batch-operated purification system is provided for removal of the high boiling compounds which are formed by the radiolytic and pyrolytic damage to the coolant. High boiling compounds (HBC) are defined as the coolant components of high molecular weight having a lower volatility than para-terphenyl, the least volatile of the components of the unirradiated coolant.

Periodically, a small portion of reactor coolant is introduced into the purification system, which is operated at a pressure of 22 mm Hg absolute. Flashing occurs within the single-plate still which provides separation of the undamaged coolant from the residue. The major portion of coolant impurities remains with the high boiling compounds.

Oil Pre-Heating

Although irradiation lowers the melting point of the coolant appreciably, the initial charge of coolant has a melting point of 200°F. and pre-heating systems are therefore necessary. For preheating purposes the insulated piping systems and vessels are provided with 60-cycle, 110v and 220v induction heating circuits. The airblast heat exchanger is preheated by use of an oil-fired furnace.

Sustained power operation of OMRE began on February 1st, 1958. From that date until September 15th,

Table II—The OMRE Coolant—Composition and Properties

Composition

Diphenyl	16.0 per cent.
Ortho Terphenyl	46.1 per cent.
Meta Terphenyl	31.8 per cent.
Para Terphenyl	6.1 per cent.

Physical Properties

	500°F.	700°F.	800°F.
Specific gravity	0.91	0.81	0.77
Specific heat, B.t.u./lb/°F.	0.52	0.59	0.60
Viscosity, centipoises..	0.46	0.23	0.17
Thermal conductivity, B.t.u./hr/ft/°F. ..	.069	.063	.061
Vapour pressure, lb/in.² abs.	5.3	42.9	94.5
Melting point range, 70-200°F.			
	260°C.	370°C.	426°C.
Specific gravity	0.91	0.81	0.77
Specific heat, gm-kal/gm°C.	0.52	0.59	0.60
Viscosity, centipoises..	0.46	0.23	0.17
Thermal conductivity, kg-cal/hr/m°C. ..	.103	.094	.091
Vapour pressure, atmospheres absolute ..	.373	3.01	6.64
Melting point range, 20-93°C.			

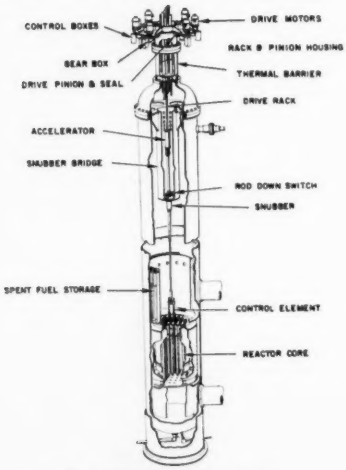
765 MWD of power operation was accumulated during a series of tests to determine the radiolytic and thermal decomposition rates and heat-transfer properties of the coolant moderator under a variety of operating conditions. During this period tests were conducted at high boiling compound (HBC) concentrations of approximately 12 per cent., 30 per cent. and 40 per cent., and at bulk coolant temperatures of 600°F. and 700°F. The fuel plate surface hot-spot temperature was maintained at 750°F. during most of the period.

Decontamination of the coolant and new build-up of decomposition product concentration to 30 per cent. were continued from September 15th to November 24th. The accumulated reactor power increased to 950 MWD during this period. The reactor was then shut down for complete clean up and removal of inorganic particulate matter which had accumulated in the system. The second fuel loading was installed.

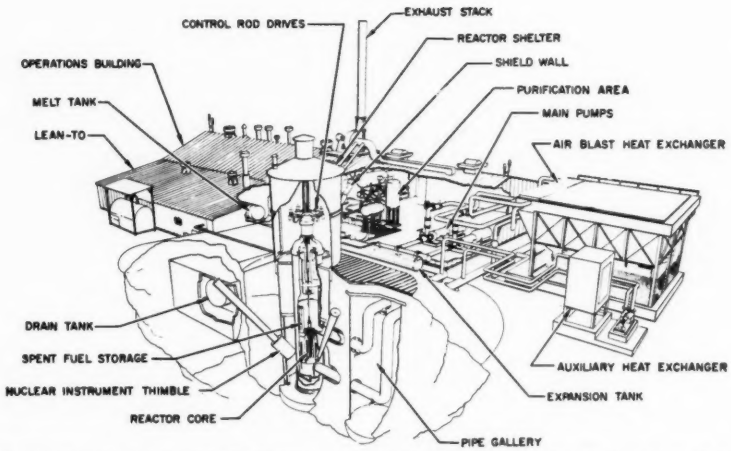
Shakedown Operation

The first test with the reactor on power operation was a shakedown of the whole system at a moderate power level and moderately high temperature. The purification system was operated to maintain the HBC concentration at 12 per cent. This test showed that a few minor modifications were required in the purification and off-gas systems. A short shutdown period was taken to perform the modifications.

The second test was done to check out the behaviour of the system at a higher temperature (700°F. bulk coolant temperature). No difficulty was encountered. Again the HBC content was held at 12 per cent. by periodic purification.



The OMRE reactor vessel



Perspective view of the OMRE Facility at the National Reactor Testing Station, Idaho Falls

After the preliminary tests were completed, the reactor was operated at conditions similar to those which will be employed in initial operation of full-scale power plants. This operation consists of two tests, both at a bulk coolant temperature of 600°F. The first test, the basic purpose of which was to determine the thermal stability of the coolant, was conducted at the minimum power level adequate to maintain the required bulk coolant temperature. This test showed that pyrolytic damage was insignificant at 600°F. The second test was performed with the fuel-plate surface hot-spot temperature at 750°F. The resultant power level was 6 MW at full coolant flow. The main objective of this test was to determine the radiolytic damage rate at an HBC concentration of 12 per cent.

HBC Build Up

Purification was then stopped and the HBC concentration was allowed to build up from 12 per cent. to 30 per cent. The bulk coolant temperature was held at 600°F. and the maximum fuel-plate surface temperature was held at 750°F. The average power level during this run was 6 MW.

With all reactor conditions the same as during the HBC build-up run, the purification system was started and the HBC content maintained at 30 per cent. for a sustained period. This test was to determine the radiolytic damage rate at the higher HBC concentration.

The purification system was again stopped and the HBC concentration was allowed to build up to 41 per cent. As the HBC content increased, it was necessary to decrease the reactor power level to 5.3 MW to maintain the maximum fuel-plate temperature of 750°F. with the bulk coolant temperature at 600°F. The decrease in power level was necessitated by a decrease in the coolant heat transfer coefficient.

When 41 per cent. HBC concentration was reached, the purification system was put into operation to maintain this concentration for a duration run. As before, the coolant temperature was held at 600°F. and the fuel-plate surface temperature at 750°F., providing reactor power level of 5.3 MW.

Manganese Isotope

After a shutdown for fuel handling operations, the radiation levels at the coolant piping showed a marked increase. It was determined that Mn-56 was the source of this radioactivity. Since it was known that Mn and essentially all coolant impurities remained with the HBC in the purification waste, the system was cleaned by extensive purification. With the reactor at a low power level (0.7 MW) to provide heat for flashing in the purification still, the HBC content was reduced from 41 per cent. to 8 per cent. At comparative reactor power levels, the coolant piping radiation levels were reduced by a factor of 2.5 during these operations.

Previous operating experience indicated that a primary area of operating interest was at a coolant HBC

concentration of 30 per cent. Therefore, in October an HBC build-up run from 8 per cent. to 30 per cent. was initiated. To provide information at different thermal operating conditions, the bulk coolant temperature was maintained at 500°F. with the fuel-plate hot-spot temperature at 750°F. These conditions provided a reactor power level of 8.6 MW throughout the run.

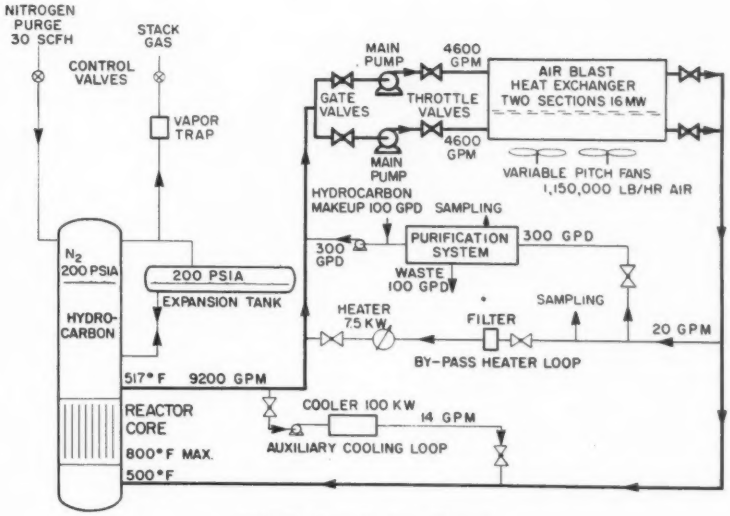
After the HBC content had reached 24 per cent. in late October, the run was interrupted when fission products were released into the coolant from one of the experimental fuel elements which had been installed in June for testing purposes. The two experimental elements were then removed and the operations were continued until late November when a 30 per cent. HBC content was reached.

As part of a programme to develop fuel elements suitable for organic power reactors, two developmental fuel elements were irradiated in the OMRE. These fuel elements had the same external dimensions as OMRE fuel elements and replaced two of them in the core lattice. The fuel material was comprised of plates of uranium-molybdenum alloy, clad with finned aluminium.

Instrumentation

Each element was instrumented with thermocouples to measure the cladding temperature and the coolant stream temperature. An indication of the coolant flow was obtained with a hot-wire anemometer installed in the lower end-plug of each element.

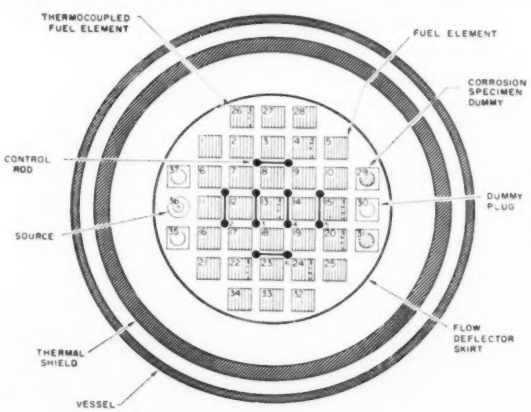
Following failure of one of these developmental elements, both were removed from the reactor and examined in a hot cell. It was observed that mostly inorganic particulate materials from the organic coolant had plugged the entrance of the coolant channels. Although the organic coolant originally loaded into the OMRE had been distilled to remove particulate matter, later coolant additions were made without prior distillation. Furthermore, the mechanical operation of a filter unit installed in the coolant system was unsatisfactory, so the unit was removed. To prevent the recurrence of a clogged element, new filters of an improved design were installed and all coolant additions are now made through the purification system to assure removal of any particulate impurities.



OMRE schematic flow diagram

Melting Occurred

Due to the reduced coolant flow through the plugged coolant channels in the developmental fuel element, the temperature of some of the fuel plates increased enough to cause the aluminium cladding and some of the uranium fuel to melt, thus releasing some of the fuel into the coolant stream. During examination of the element it was also observed that, with the exception of the plates which melted due to the restricted coolant flow, the other fuel plates showed negligible dimensional change from radiation damage. The highest burn-up estimated for these plates was 3,000 MWD/tonne.



Core layout of the OMRE at Idaho Falls. To measure cladding temperatures and coolant stream temperatures all fuel elements are equipped with thermocouples

Upsurge of Radiation

During a period of steady operation on October 23rd, 1958, a very sudden increase took place in the radiation levels throughout the OMRE system. Fission products were identified in the coolant. They were completely contained in the system and there was no release to the atmosphere. It was later estimated that approximately 1,000 curies of fission product activity had been introduced into the coolant and gas blanket.

All of the fission products detected in both coolant and blanket gas samples immediately after the release were volatile or had volatile precursors. The iodine isotopes, although volatile, became chemically bonded and remained with the coolant. Since xenon was the only isotope detected in the blanket gas, it was vented to the atmosphere at a controlled rate under safe meteorological conditions. Within a few days the only fission products present in the coolant in any significant quantity were I-131, Ba-140 and La-140. The radiation levels from these fission products were sufficiently

low to allow resumption of normal reactor and maintenance operation a few days later.

Results of the tests showed that 7.8 per cent. of the OMRE energy is absorbed in the moderator-coolant. In full scale plants the energy absorption would amount to only about 4 per cent. This decrease results mainly from the use of low enrichment aluminium clad fuel elements and from high metal-to-coolant ratios. Under these conditions the cost of coolant makeup required for makeup replacement of radiolytic damage products is estimated at less than 0.7 mill/kWh, at a coolant cost of $0.17/lb.

Inorganic Impurities

As anticipated the radiation levels at the coolant piping are due mainly to the inorganic impurities present in the virgin coolant or removed from the walls of the vessels and piping. The most important radioisotope impurities which have been observed are Mn-56, Fe-59, P-32 and S-35. Activation of these impurities results in low radiation levels at the surfaces of the reactor coolant piping and in the work area around the process equipment.

Radiation Levels

The highest radiation level measured in the process area during operation of the reactor at a power level of 10 MW was 80 mr/hr. This was the level at the surface of the 10 in. pipes and at the surface of the filter removing the particulate matter from the system. The radiation level in the centre of the area was 13 mr/hr, less than twice normal tolerance. Airborne activity was at times well below breathing tolerance.

Throughout operation of the reactor on its first fuel loading, the heat transfer coefficient of the irradiated OMRE coolant was measured in an electrically heated by-pass coolant loop. As the HBC content increased to 40 per cent., there was a slow and gradual decrease in the heat transfer coefficient.

Experience gained with the OMRE has more than confirmed the expectations of Atomics International scientists and has conclusively demonstrated the feasibility of an organic moderated and cooled power reactor. The low decomposition rates of the coolant and the absence of deposited decomposition products on the heat transfer and other system surfaces have assured the practicability of the concept. The operation has provided the operating experience necessary to verify the predicted novel construction and operating features, low operating pressure, reactor stability and safety, and use of standard lightweight materials of construction.

References

TRILLING, C. A., "The OMRE—A Test of the Organic Moderator-Coolant Concept." 2nd Int. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1958.

SWANSON, N. J., and MULLER, D. R., "OMRE Operating Experience." Atomics International, a division of North American Aviation, Inc.

Laboratory for Studying N-Materials

(*Continued from page 394*)

Changing the laps and moving the specimen from one machine to another is done by the handling tongs.

The specimen is afterwards transferred to the third cell which is equipped for attack-polishing, electro-polishing and anodizing.

The fourth cell is, at present, a spare one, but forms a useful temporary storage space for specimens which may be awaiting attention or which are being kept for future reference.

In the fifth or end cell is a variable-load hardness testing machine, and a Reichert microscope, modified for remote control, on which a full metallographic examination can be carried out. This microscope has all its controls on a control panel outside the cell, and the image formed by the microscope is also brought out through the walls of the cell, by means of an optical system, to a camera located outside. This optical system is arranged to have two right-angle bends in it to obviate any direct paths for the emergence of radiation from the interior of the cell. Thus a complete metallurgical examination can be carried out, and a photographic record obtained of the results, on radioactive specimens without any danger to the operators.

Decontamination work is carried out in a small room which has direct access to the laboratory and rear of the caves. Changing rooms for the exclusive use of personnel using the area are provided and the floor, which slopes down to a sump, is covered with PVC. An observation window is set in the wall so that operations within the room can be observed and controlled by an operator outside the room.

Effluent Treatment

Contaminated water from the cells, caves, and decontamination area is conveyed by copper pipes to the chamber at the south end of the main laboratory. Here it is filtered through batteries of ceramic candle filters located in a screened cell, and then passed through an expendable-cartridge type ion exchange unit, after which it is pumped into a holding tank.

There are five holding tanks, two for contaminated water from the cells, caves and decontamination area, two for effluents from sinks and wash-basins and one spare. Decontaminated filters and ion exchange units will be disposed of by arrangement with the UKAEA.

The caves and cells are served by hot and cold water and compressed air, and there are arrangements for the supply of other fluids and of hot air for drying purposes.

An Eye on Safety

Adjacent to the main laboratory is the health physics laboratory, whose staff are responsible for checking the safety of all operations carried out in the building and for keeping a continuous watch on radioactive contamination levels. Equipment includes a scintillation counter for measuring residual activity in the water in the effluent holding tanks, a continuously running monitor for measuring residual activity in filtered air from the cells, hand and clothing monitor, and other usual health physics apparatus.

With the nuclear metals laboratory Metropolitan-Vickers will be able to learn a considerable amount about the behaviour of reactor components. Among work planned are studies on various aspects of the full element assemblies and sub-assemblies to be used in the Berkeley nuclear power station, the effect of irradiation on zirconium and the effect of irradiation on the components of fuel coolant temperature measuring circuits and control rod systems.

Thorium

Separation from Monazite

By M. Z. HATHOUT, BSc, PhD

Assiut University, Egypt

UP to the years immediately following the 1914-18 war the importance of thorium was due to the extensive use of gas mantles. These contained the element in the form of thorium oxide or thoria, together with a small proportion of cerium oxide. With the increasing use of electricity for lighting thorium production steeply declined and it is only since the development of nuclear reactors that interest in its production and purification has been revived.

The importance of thorium in nuclear energy is that it is the most abundant element available in reasonable concentrations in nature that can undergo fission and produce on decay the fissile material U-233. Stages in this process are as follows:

$$Th^{232}(n, \gamma)\ Th^{233} \xrightarrow[23.3\ min]{\beta^-} Pa^{233} \xrightarrow[27.42\ days]{\beta^-} U^{233}$$

Contaminants Removal

Purity requirements of thorium depend upon its ultimate use. In order to obtain a favourable neutron economy in thorium that is to be irradiated the removal of contaminants with a large thermal neutron absorption cross-section is necessary. In general, however, this step is less important for thorium than for uranium. Metal approaching a suitable analysis can be made from unextracted commercial thorium nitrate.

Although thorium is widely distributed in nature, rich deposits are scarce. Traces of thorium have been found in more than 100 minerals, a few of which contain more than 1 per cent. thorium. Among the minerals that contain an appreciable amount are thorite ($ThO_2.SiO_2$) and thorianite ($ThO_2.UO_2$). Deposits of these, however, have not yet been encountered.

This leaves monazite, which is separated from the blacksands in India, Brazil, United States of America and Egypt, as the only commercially feasible source of thorium, although the content of thorium is less than 10 per cent. (from 3 per cent. to 10 per cent., in fact).

Some typical analyses of monazite sands are given in Table I.

The physical and chemical constants of thorium are as follows:—

Density:—
Theoretical (X-ray): 11.71 gm/cm³
Ames casting: 11.55-11.63 gm/cm³
Melting point: 1,690°C. ± 10°C.
Boiling point: Over 3,000°C.
Specific heat:—
99.3°C.: 6.59 cal/(mole) (°C.)
198.7°C.: 6.61 cal/(mole) (°C.)
Entropy—25°C:
13.6 ± 0.8 cal/(mole) (°C.)

Thorium closely resembles tetravalent cerium in its chemical properties but is somewhat more electropositive. Hydrolysis of the thorium ion is rather less than that of the other tetrapositive cations. Soluble thorium salts stay in solution even at acidities below 0.01*N*.

Separations Facilitated

The combination of high charge and low hydrolysis makes the thorium ion particularly readily absorbable on cation exchangers. Separations from other cations are thus facilitated, and trace amounts of thorium can be concentrated. For example, it is possible to separate the isotope Th-234 and then elute the other thorium isotopes with oxalic acid. This process in theory could be applied to the separation of thorium from the rare earths, but is limited by the low absorptive capacity of the ion exchanger. In this respect, the purification by extraction with immiscible organic solvents is greatly superior.

Benzene Extraction

Thorium shows a strong tendency to form complexes with anions. Complexes with chelating agents are also readily formed. The best of these has been found to be the diketones of the acetyl-acetone type. Complexes with this type of reagent are often extractable in solvents like benzene.

The rare earth elements exist in compounds generally as cations in a 3+ state. Stability of exactly full energy levels in the rare earths group is shown by the occurrence of the 4+ ions of cerium.

The 3+ ions of the rare earth elements and the 4+ ions of cerium are the only rare earth ions that exist in water solution.

The radius of the 3+ ions of the rare earths decreases steadily from 1.15A for lanthanum, down to

TABLE I—Typical analyses of monazite sand

	Indian	Brazilian	Idaho
	per cent.	per cent.	per cent.
Total R.E. oxides	69.2	68.1	68.9
ThO_2	9.4	6.5	3.95
CeO_2	28.5	—	29.2
U_3O_8	0.37	0.18	0.15
P_2O_5	25.9	26.0	28.5
SiO_2	7.0	—	3.14
Pb	—	2.2	0.01

Thorium content of the sand is usually less than 10 per cent. The rare earths comprise about 60 to 65 per cent. Uranium content is usually less than 0.5 per cent.

0.89A for lutecium; conversely, the charge density increases from lanthanum to lutecium. In other words, the rare earth ions of high atomic number and small size will have less electrons and be more acidic. Lanthanum and cerium, first in the rare earth group, for instance, are the least acidic of the group and hence will precipitate first when a solution containing their salts is neutralized. The greater part of the rare earths in monazite sand contains lanthanum and cerium.

Acid Digestion

Several methods for the extraction of thorium compounds from monazite sand are available. The usual commercial method is to digest the sand with excess concentrated sulphuric acid. A thick paste results which is stirred gradually into additional water and allowed to settle. The solution contains the bulk of the thorium and rare earths as phosphate complexes.

The thorium is separated either by partial neutralization to effect fractional precipitation of the thorium phosphate, or by a carbonate separation, which is based on the fact that thorium carbonate is much more soluble in excess sodium carbonate than are the carbonates of the rare earths. An oxalate separation based on the solubility of thorium oxalate in an ammonium oxalate solution has also been tried successfully.

Digestion of the monazite sand with caustic soda and solvent extraction of the thorium has been carried out on a pilot plant scale, but has not yet been applied to commercial production. Solvent extraction of thorium after digesting the monazite sand with sulphuric acid also has been studied.

Ames Process

In this article I will consider the Ames process, which is the primary method of production of thorium. This is a sulphuric acid digestion followed by dissolution of the pasty mass that results in cold water and fractional neutralization.

A flowsheet of this process is shown in Fig. 1. The process consists of three main operations:—

1. Digestion of sands.
2. Dissolution of digested mass.
3. Precipitation of:
   (*a*) Thorium.
   (*b*) Rare earths.
   (*c*) Uranium.

The digestion of the sands is carried out with sulphuric acid. The variables that have been studied for optimizing include:

(i) Amount of acid needed.

(ii) The concentration of the acid used.

(iii) The temperature at which highest rate of digestion is obtained.

(iv) Time needed for completion of the digestion.

Results of the work carried out by Blickwedel[1] and Shaw[2] at the USAEC Ames laboratory are summarized as follows:—

Blickwedel reported:

1. For purpose of getting a soluble thorium product, a weight ratio of sulphuric acid:sand (basis 100 per cent. H_2SO_4) of 2:1 has been reported;

2. He found that complete decomposition could be secured with ratios of H_2SO_4:sand as low as 2.5:1 with acid of 95 per cent. concentration at a temperature of 200°C. (Table No. II). (It was also found that an insoluble compound of thorium begins to form at digestion temperatures over 215°C.);

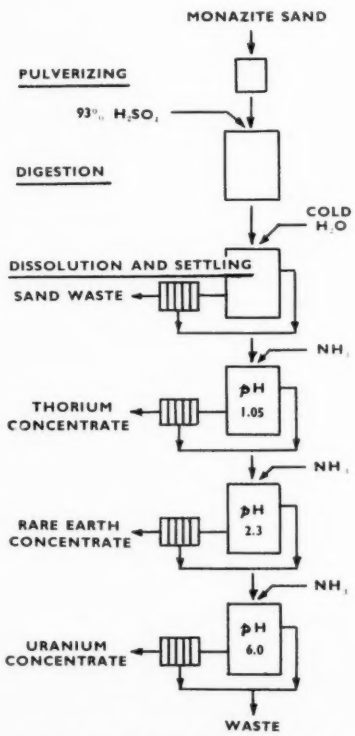


Fig. 1. Flow sheet of Ames method of thorium production.

Acid concentration H_2SO_4 per cent.	Per cent. of monazite decomposed
90	99.2
93	99.4
95	99.6
98	99.3

1. Temperature of digestion . . 200°C.
2. Time of digestion . . . . 2 hr
3. Acid/sand ratio 2.5
4. It was difficult to obtain good mixing at low ratios of acid/sand.

TABLE II—Effects of acid on various concentrations in decomposition of monazite sands.

3. Of particular interest was the discovery that an acid concentration of 93 per cent. gives optimum decomposition under a given set of conditions;

4. For the purpose of decomposing monazite to secure a solution from which thorium can be extracted, it is recommended that 93 per cent. sulphuric acid be used with a weight ratio of acid:sand::2.1:1 at a temperature of 200°C.;

5. If the solution is to be heated or greatly diluted (as may prove necessary in liquid-liquid extraction), a higher ratio of acid to sand with subsequent excess acid will be necessary to prevent formation of a thorium precipitate. Precipitation was found to be prevented by the addition of H_2SO_4 to the solution after the digestion and before dilution or heating.

Shaw reported:

1. The minimum acid:sand weight ratio, based on the stoichiometry of the reaction, is about 0.60. (This is discussed in a later section of this article);

2. The actual minimum acid:sand weight ratio was limited by the solubility of the thorium phosphate in the resulting monazite sulphate solution;

3. The actual minimum acid to digested sands ratio was 1.60 for both Indian and Idaho monazite sands;

4. The best procedure for carrying out the digestion was to add the monazite sand to sulphuric acid at about 204°C.;

5. The time of digestion depended primarily upon the particle size of the sand. If the sands were finely

ground, the reaction was complete in about one hour. If the sands were quite coarse, four to six hours were required.

As the reaction proceeds in the digestion reactor, the digested mass becomes more and more viscous. When the reaction is complete a pasty mass results.

Dissolution of the digested mass is accomplished by adding 10 lb of water/lb of sand digested. Cold water is preferable because the rare earth sulphates are more soluble at low temperatures than at high temperatures.

Decantation

The resulting solution is stable and very close to saturation with respect to the rare earths and thorium. This solution is what is referred to as "monazite sulphate solution."

The monazite sulphate solution is separated from the undigested sand by decantation or syphoning. The undigested sand is recycled to dissolve any thorium or rare-earths left or trapped in it, while the monazite sulphate solution is left standing to allow any suspended solids to settle out.

The settled fines are mainly silica with a very large fraction of the radioactive daughter products of thorium and uranium and they are disposed of as solid waste after decanting the monazite sulphate solution.

Precipitation of the thorium can be attained by either dilution or neutralization with an alkali.

Mere dilution with water would cause the thorium to precipitate, but very large amounts of water, about 300 lb of water/lb of monazite sulphate solution, are required for complete precipitation. Because of the voluminous nature of the precipitate, large amounts of rare earths are retained.

NH_4OH Preferred

Tests were carried out in the Ames laboratories to select a neutralizing agent to precipitate the thorium selectively from the monazite sulphate solution. In these tests the monazite sulphate solution was diluted with 4.2 parts of water. As shown in Fig. 2, ammonium hydroxide was found to be preferable to sodium carbonate because a smaller amount of rare earths would be co-precipitated. At a *p*H of about 1.0, nearly complete precipitation of the thorium, accompanied by only about 5 per cent. of the rare earths, was accomplished when ammonium hydroxide was used.

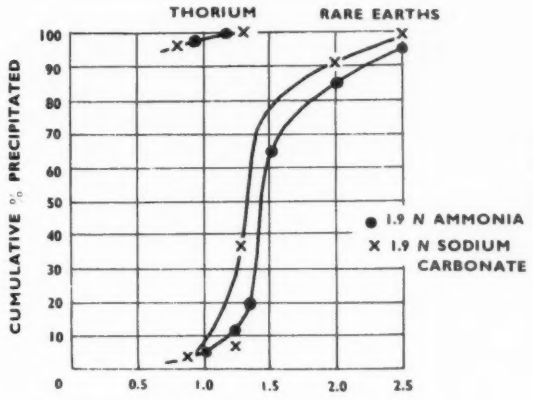


Fig. 2—Comparison between precipitation of rare earths with ammonium hydroxide and sodium carbonate

Since the rare earths are present in much larger amounts, the resulting precipitate was about half thorium phosphate and half occluded rare-earth sulphates.

The solids are then allowed to settle and the clear solution decanted. The precipitate is filtered and the cake is purified by liquid-liquid extraction, most probably, or by ion exchange resin.

The filtrate and the clear solution are then sent for further neutralization to precipitate the rest of the rare earths and uranium.

Using the same reagent, ammonium hydroxide, to adjust the *p*H value to 2.3, the rare earths are precipitated; a further adjustment of the *p*H value, to 6.0, precipitates the uranium and remainder of the rare earths.

In dissolution or digestion there are three possible series of reactions. To each of these reactions, the weight ratio of acid:sand was calculated from the stoichiometry of the reactions. The values favoured the last case as the acid:sand ratio

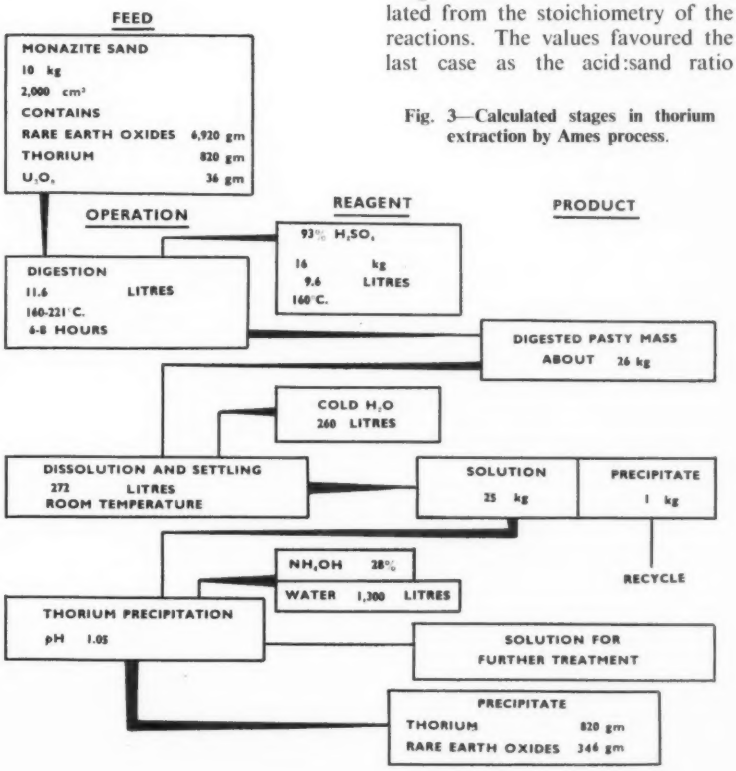


Fig. 3—Calculated stages in thorium extraction by Ames process.

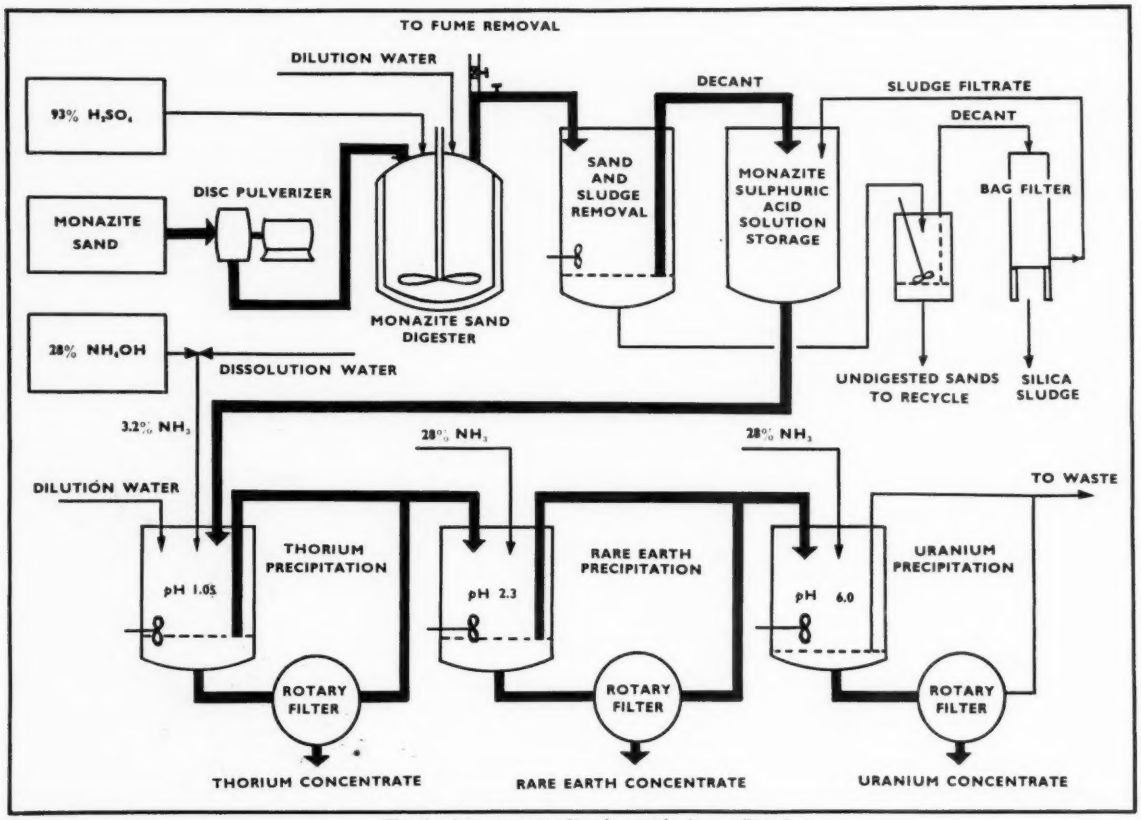


Fig. 4—Arrangement of equipment in Ames pilot plant

in this approached that given by Shaw, whose assumptions were based on more chemical data than is available here.

The three series of reactions are:—

Case A:

$$ThO_2 + 2H_2SO_4 \rightleftharpoons Th(SO_4)_2 + 2H_2O$$

$$CeO_2 + 2H_2SO_4 \rightleftharpoons Ce(SO_4)_2 + 2H_2O$$

$$R_2O_3 + 3H_2SO_4 \rightleftharpoons R_2(SO_4)_3 + 3H_2O$$

The acid:sand ratio is 0.755

Case B:

$$CeO_2 + 2H_2SO_4 \rightleftharpoons Ce(SO_4)_2 + 2H_2O$$

$$R_2O_3 + 3H_2SO_4 \rightleftharpoons R_2(SO_4)_3 + 3H_2O$$

$$ThO_2 + H_3PO_4 \rightleftharpoons Th_3(PO_4)_4 + H_2O$$

The acid:sand ratio is 0.685

Case C:

$$Ce_2O_3 + 3H_2SO_4 \rightleftharpoons Ce_2(SO_4)_3 + 3H_2O$$

$$R_2O_3 + 3H_2SO_4 \rightleftharpoons R_2(SO_4)_3 + 3H_2O$$

$$ThO_2 + H_3PO_4 \rightleftharpoons Th_3(PO_4)_4 + H_2O$$

The acid:sand ratio is 0.614

All to 100 per cent. H_2SO_4.

Basis:

The value given for the acid:sand ratio by Shaw is 0.60; the atomic weight of the rare earths was taken as the mean of that of lanthanum and niodinium, i.e., 142.0.

From this it is justifiable to assume:—

1. The thorium is present in the monazite sands as the phosphate rather than silicate, the alternative given in the textbooks of chemistry and mineralogy; and

2. The cerium is present in the 3+ state rather than the 4+ state.

There are three methods for the determination of thorium in monazite sand. They are all gravimetric methods. The time consuming operation is the digestion and dissolution of the sands.

(*a*) Hexamine method: range 0.5 per cent. to 10 per cent. ThO_2;

(*b*) Iodate method: range 0.5 per cent. to 10 per cent. ThO_2;

(*c*) Rapid method in which all interfering elements except titanium are removed by precipitation with sodium pyrophosphate, sodium hydroxide and hexamine. The amount of titanium that follows through to the final precipitation is determined colorimetrically by hydrogen peroxide treatment. The thorium and titanium are then precipitated with peroxide and ignited to the oxides[3].

On the basis of the pilot plant runs made at the Ames laboratory on a sample of Indian monazite, calculations were carried out, the results of which are shown in diagrammatic form in Fig. 3. Digestion of the sands was carried out in 10 kg batches.

Weights and volumes of the sands, rare earth oxides, monazite and acid used in the runs are as follow:—

Fraction or element	Weight, gm	Volume, litres
Total R.E. oxides	6,920	
Th (not ThO_2) ..	820	
U_3O_8	36	2.0
P_2O_5	2,590	
SiO_2	700	
H_2SO_4 (93 per ct.)	16,000	9.6
		11.6

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[1]BLICKWEDEL, T. W., USAEC Report ISC-66 (November 12th, 1949).

[2]SHAW, K. G., SMUTZ, M., and BRIDGER, G. L., USAEC Report ISC-407 (January, 1954).

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Safety Aspects of

WORKING WITH PLUTONIUM

by Arthur B. Shuck

Argonne National Laboratory

THE hazards of working with plutonium are a consequence of four properties of the element—(*a*) it can become critical, (*b*) it emits alpha particles, (*c*) it can constitute a radiation hazard, and (*d*) it is, in certain forms, pyrophoric, combining spontaneously and energetically with oxygen and producing sufficient heat to ignite combustible materials in its environment. The Fuel Fabrication Facility recently put into operation at the Argonne National Laboratory, Lemont, Illinois (see NUCLEAR ENERGY ENGINEER, July, 1959, for details) is designed to allow maximum control of the hazards arising from these properties.

Criticality is a characteristic of all nuclear fuels. It may be defined as the minimum mass of fissionable isotope required under a given set of conditions to initiate a nuclear chain reaction. The term is somewhat misleading in that criticality is not a factor of mass alone, but is influenced by shape, dispersion, energy of the neutrons, kinds of materials in which the fissionable isotopes are dispersed, and materials surrounding the fissionable material which may reflect neutrons. The three fissionable isotopes of importance as reactor fuels are U-235, U-233 and Pu-239.

"Always-Safe" States

Two concepts of safety are used in evaluating work with critical materials. One is the concept of "always safe mass." The second is the concept of "always safe geometry." The "always safe mass" is the amount of fissionable isotope which, regardless of shape, dispersion, moderation or reflection, cannot sustain a nuclear chain reaction. Work with quantities below the "always safe mass" provides the maximum of protection for the workers, provided of course that two or more such masses are not brought close enough together to form a critical system. Since much of the processing of uranium and plutonium is done in ordinary light water solutions, which is both an excellent moderator and reflector of neutrons, the "always safe mass" is a concept of great practical importance.

To Prevent Criticality

The critical mass geometry and dispersion-in-water values for the three nuclear fuel isotopes, as outlined by Henry[1], are shown in Table I. The values in this table were developed for pure fissile materials surrounded by a thick water reflector. Solution values are for solutions in ordinary water. Metal values are for rectangular masses of metal.

The "always safe mass" of fissionable material is usually taken as slightly less than one-half of the figures shown in the table; hence, an accidental combination of two always safe masses cannot cause criticality.

The plutonium as received at the Argonne Facility contains isotopes other than Pu-239 and also impurities. Safe critical mass of this "commercial" plutonium is taken as being about 300g (10.6 oz).

It is possible and often necessary to work with several thousand grams of plutonium provided that attention is paid to the materials in which the plutonium is contained, to how the plutonium is dispersed, and to the geometric shape of the plutonium. This is the concept of "always safe geometry."

It is important to guard against conditions under which the system might become critical. For instance, 3,000 g (6.6 lb) of solid "commercial" plutonium is considered safe as a single piece even though it is accidently flooded with water. Dispersion in a moderating medium (which slows down neutrons, allowing them to react more easily with plutonium atoms) would cause the same amount of plutonium to be supercritical. If a larger piece of plutonium were handled, flooding might cause a chain reaction. Flooding with water provides neutron reflection and must be avoided where

Table 1.—Values of Nuclear Variables

Basic nuclear parameters	U^{235}		U^{233}		Pu ^{239}	
	Minimum critical	Safe	Minimum critical	Safe	Minimum critical	Safe
Mass (kg)—						
Solution	0.80	0.35	0.59	0.25	0.51	0.25
Metal	22.8	11.0	8.0	3.0	5.6	2.6
Cylinder diameter (in.)—						
Solution	5.5	5.0	4.5	3.7	5.0	4.5
Metal	2.9	2.5	—	1.5	—	1.4
Slab thickness (in.)— ..						
Solution	1.7	1.5	—	0.5	—	1.5
Metal	0.75	0.65	—	0.2	—	0.2
Volume (litres)—						
Solution	5.9	4.8	3.5	2.0	5.0	3.3
Concentration (gm/litre)—						
Solution	11.6	5.0	10.9	4.7	7.3	3.2

substantial quantities of plutonium are processed or machined.

Flooding is prevented in the Fuel Fabrication Facility process enclosures by pumping the water used for cooling equipment in these enclosures at sub-atmospheric pressure. Water is sucked rather than pushed through the cooling pipes. A break in one of these pipes would cause the process enclosure atmosphere to be drawn into the water cooling system, but the enclosures would not be flooded.

Watch Geometry

It is possible to work with pieces of plutonium metal which in a compact state would be supercritical, provided that attention is paid to their geometry. Thus a $^{3}/_{16}$ in. plutonium plate of any size or a 1.4 in. diameter rod of any length is safe even though the total mass is many times the always safe mass.

The above considerations apply to isolated masses. Obviously plutonium plates or rods cannot be stacked without violating the principle of "always safe geometry." The effect of interaction between safe masses spaced some distance apart must also be considered, particularly when a neutron slowing or moderating material might be placed between the masses. Storage vaults present a special problem in this respect in as much as many shapes and sizes of pieces, and dispersions of plutonium in other materials, have to be stored.

Danger From Humans

It is conceivable that the moderating effect of the body of a human worker entering the vault might moderate or reflect enough neutrons to cause criticality. This is guarded against by arranging the vault stacks in cubicles and by limiting the quantity of plutonium stored in any cubicle. The spacing between stacks of shelves is also calculated so that if the shelves are loaded to capacity, the body of the custodian does not cause a nuclear chain reaction. The number of persons allowed at any time in a vault may also be limited. Special care must be taken so that vault shelves cannot collapse or be tipped against one another.

Fire in a vault presents a serious problem. Firemen must be prevented from flooding the vault with water both for reasons of criticality and because of the violent chemical interaction between water and many plutonium alloys. Neutron absorbers (or poisons) are sometimes used in vaults to reduce the flooding hazard potential.

Since all persons working with fissionable materials are not nuclear physicists experienced in the problems of criticality, the practice is to prepare a careful analysis of all operations exceeding the always safe mass of fissionable material. A detailed programme of work to be done is planned in advance. A report is prepared showing how the work will flow, how much plutonium there will be at a given place at a given time, and how the fuel being studied or manufactured will be composed. Internal moderators and neutron poisons are described in the report. The physical arrangement of the equipment and materials of construction for special laboratory equipment such as crucibles are also described.

So that possible interactions may be studied, a motion study and transportation plan are essential when many items are to be processed. Often the plan is carefully rehearsed using inert materials. The reports and rehearsals are carefully studied by a committee of scientists and engineers experienced in the analysis of criticality problems. Only after their approval is received can the work begin.

Unfortunately, there is no effective or practical instrumentation for monitoring approaching criticality in a process plant. Close administrative control is necessary over all processes and personnel to see that safe procedures are followed and that careless habits do not develop.

Stopping the Alphas

Plutonium emits three forms of radioactivity: alpha particles, gamma or X-ray and neutrons. Of these, alpha particle emission, because of its intensity, is of greatest consequence. Alpha particles emitted by plutonium have an energy of 5.15 MeV and a mean range in air of 3.68 cm. They are stopped by a thin film of plastic or metal foil or by human skin and so do not constitute a hazard as external radiation. However, they are very heavy particles and over their short range do extreme damage in biological tissues.

The danger from plutonium and other alpha particle emitters comes from their possibility of being inhaled, ingested, or introduced through cuts or skin lesions. Unfortunately, plutonium is not completely eliminated from the body by natural processes and becomes fixed in tissues of the body, particularly bone tissues, where its strongly ionizing radiation causes extreme damage.

The National Committee for Radiation Protection[2] has set 0.13 micrograms (13 hundred millionths of a gramme) as the maximum permissible limit of insoluble plutonium in the human body.

Safe Handling Essential

Uranium too is an alpha emitter, but plutonium emits about five million times as many alpha particles/gramme as does U-238 or thorium. So while U-238 or thorium can be handled with about the same degree of precaution as any toxic metal, plutonium must be handled as though it were thousands of times more toxic than the most dangerous of industrial poisons.

In ordinary moist air, plutonium tends to form a finely divided, loosely held oxide which has a remarkable ability to pass into the air and to remain airborne. The National Committee on Radiation Protection[2] has established a maximum permissible limit of 2.0×10^{-12} microcuries of plutonium/millilitre of air. Calculated in terms of gramme concentration this becomes 32 trillionths of a gramme/m^3 of air.

Work in Glove Boxes

From the very low maximum permissible limit of plutonium in air, it is evident that unless the plutonium is contained in a gas-tight container, or fixed in a non-oxidizing alloy, it is necessary to completely separate the atmosphere exposed to the plutonium from the air breathed by the operators. This is commonly done by enclosing the work spaces and equipment in glove boxes. Arm length neoprene gloves are sealed through the walls of these enclosures. Because the inside of these enclosures becomes very highly contaminated, it is necessary when designing this equipment to achieve a high degree of tightness.

The associated ductwork, piping, electrical lines and process equipment which penetrate the walls of

the enclosures must be made gas-tight to the outside. In the Fuel Fabrication Facility, a leakage rate of 0.02 cu.ft of gas/hr/100 cu.ft of enclosed space at a negative pressure of 2 in. water gauge was the maximum allowed. Leaks were hunted using helium sensitive mass spectrometer leak detectors.

A second method of controlling the leakage of plutonium contamination from the enclosure is to maintain the inside of the glove box at a negative pressure with respect to the room atmosphere. About 0.8 in. water gauge is the maximum differential pressure recommended; above this figure the gloves tend to inflate on the hands of human operators, making manipulation very clumsy.

Double Gloving

Customarily, two pairs of rubber gloves are worn by the operator in the Fuel Fabrication Facility. A heavy synthetic rubber glove is clamped to a port in the wall of the glove box. The operator wears thin surgical gloves on his hands to afford secondary protection in case the heavy gloves become snagged or cut. Great care is taken to prevent penetration of the gloves by sharp or hot objects. This is particularly important in a metals fabricating plant where many high temperature operations must be performed. For the sake of safety as well as production, as many operations as possible are mechanically performed.

To prevent contamination of the room, techniques have been devised for changing gloves and filters and for moving items into and out of the glove boxes without opening them. An object to be transferred is placed in a heavy vinyl pouch gasketed to a port through the wall of a hood. Three dielectric heat seals are made between the port and the object. The centre seal is cut, separating the envelope containing the object to be removed from the glove box line. This leaves a somewhat shorter closed pouch still attached to the glove box line ready for the next transfer. This technique prevents contamination of the room and leakage of air into an inert gas filled glove box. It also provides a small balloon of inert atmosphere for those items which cannot be exposed to the air.

Until recently, radiation from plutonium other than alpha emission has not been considered a serious hazard. In general the plutonium isotopes are rather weak sources of soft X-rays. With increase in reactor exposure, and subsequent increase in the percentage of higher plutonium isotopes which decay into radioactive daughter products, the amount of gamma and X-rays has tended to increase. In some cases it is now necessary to limit hand exposure or to wear gloves loaded with lead in order to stay within maximum permissible limits of exposure.

Dealing With Neutrons

The neutron problem is a consequence of the alpha-neutron reaction with the elements beryllium, boron, lithium, nitrogen, fluorine, sodium, magnesium or aluminium. The alpha-neutron reaction with fluorine may produce a sufficient intensity of neutrons to be a consideration in the chemical processing of plutonium. An alloy of plutonium with beryllium is a commonly used neutron source. Some consideration should be given to the neutron problem in preparation of alloys and in the selection of crucible materials in which to heat plutonium.

An additional consideration in handling and fabricating plutonium and its alloys is the fact that under certain conditions they constitute a considerable fire hazard. This hazard is compounded by the criticality and radioactivity problems, making a major fire in a plutonium facility extremely difficult to control.

Fires Might Start

Fairly large pieces of unalloyed plutonium metal may be handled with reasonable safety. The danger of fire results from:—

1. Finely divided materials such as turnings and powders;

2. Unstable and mechanically sensitive hydrides (compounds which may form in moist atmospheres);

3. Spontaneously pyrophoric alloys and intermetallic compounds; and

4. Spontaneous ignition of impure metallic residues, such as partially oxidized crucible skulls.

Plutonium, like other materials, possesses an ignition temperature below which it oxidizes so slowly that the heat of oxidation does not maintain combustion and above which oxidation progresses very rapidly. The ignition temperature varies with the form and composition of the plutonium containing material. Many metallurgical operations with plutonium, such as melting, heat treating, and hot working, must be carried out at temperatures above the ignition temperature. Provision must be made to exclude oxygen when such operations are performed. This is conventionally done in furnaces or containers which are evacuated or flooded with inert gas. Occasionally, in the past, isolated glove boxes have been provided with a protective inert gas atmosphere.

Since 1954, a small plutonium research laboratory has been in operation at Argonne National Laboratory incorporating a system of gas-tight interconnecting glove boxes which are supplied with a continuously recirculated and purified helium atmosphere[3]. The special techniques developed for this system provided an unequalled record of contamination safety. These techniques so successfully minimized the hazards of fire and oxidation that the requirement of an inert atmosphere was made for the new facility.

Water No Good

A plutonium metal fire cannot be fought with water because of the problem of criticality and because water in contact with hot reactive metals releases large amounts of hydrogen which can result in a secondary explosion. Carbon dioxide is of doubtful value in fighting metal fires. Exclusion of air seems to be the only effective fire fighting procedure which has been developed to date. Dry extinguishers, such as powdered carbon and powdered silica, have been recommended. Because of the alpha radioactivity hazard, fire fighters must be equipped with suitable protective clothing and supplied air masks—preferably " frogman " suits.

Because fire is a serious hazard in a plutonium facility, an effective fire warning device was considered essential in each glove box line of the Fuel Fabrication Facility. A pneumatic temperature rise rate detector developed by the Walter Kidde Corporation was selected. The system installed consists of thin-wall copper tubing passing in a loop below the ceiling of each glove box line through seals in the ends of the line. The tubing then passes in a loop through the housing below the glove boxes.

Gas in the tubing is allowed to escape at a calibrated rate as it expands under normal changes in temperature. In case of fire, the expansion of gas is so rapid that it cannot escape the tubing; the increased pressure closes a bellows switch which sounds the fire alarm. Each hood line is so equipped.

Storage vaults for radioactive materials are provided with tubing on the underside of each alternate shelf as well as below the ceiling of each vault. The system is also extended to laboratory rooms and offices of the entire building. The fire signal operates alarms throughout the building; panel indicator lights show the location of the fire. Relays transmit signals to the Argonne plant security and fire protection departments where the location of the fire is indicated by a code print out machine.

Importance of Staff

Only so much safety can be built into a plutonium facility. In the long run, safety of operation depends upon the planning and organization of the operations and upon the skill and training of the technicians and staff. Standards of safe operation must be carefully formulated and then put into practice through careful indoctrination of operating personnel. The standards must not be allowed to deteriorate through lack of supervision or discipline.

Article is supplied by Argonne National Laboratory, Lemont, Illinois.

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[1]HENRY, H. F., "Basic Principles of Nuclear Safety" K-1380—*Studies in Nuclear Safety*, Oak Ridge Gaseous Diffusion Plant (1958) page A20.

[2]U.S. Department of Commerce, Bureau of Standards Handbook 52—"Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water."

[3]KELMAN, L. R., WILKINSON, W. D., SHUCK, A. B., and GOERTZ, R. C., "The Safe Handling of Radioactive-Pyrophoric Materials," Report *ANL-5509*, pp. 11-13.

Student Training Reactor

Nuclear engineering laboratory equipped with new sub-critical reactor—Model 9000. Reactor is seen on left, centre is a neutron "howitzer". Other equipment includes an automatic neutron flux scanner

THE Nuclear-Chicago Corporation in the United States has recently developed a completely new type sub-critical reactor. Called "Model 9000," it is entirely for educational purposes—for use in schools, colleges and universities. It is a water moderated, natural uranium assembly. The vital parts—uranium, water and neutron source—cannot be arranged in any possible way such that the device can become critical. Model 9000 is thus inherently safe, requires no complicated shielding, costly cooling system, operator licensing, or involved safety programme. Its primary function as a teaching tool makes it constantly available for student use.

A stainless steel tank, 4 ft in diameter × 5 ft high, forms the reactor vessel. The tank contains 370 gal of water which act as a moderator and shield. Immersed in the water is a lattice-like arrangement of 271 vertical aluminium tubes held in place by two grid plates located near the bottom of the tank. Each tube contains five aluminium jacketed natural uranium rods about 8 in. long × 1 in. in diameter. A neutron source such as plutonium mixed with beryllium is placed at the centre of the uranium lattice to initiate and maintain the chain reaction. The fission process in the assembly results in a multiplication of the neutron flux from the source by a factor of six to seven.

The open construction of the reactor provides easy access to its internal parts for experimentation and instruction. The lattice configuration, the uranium rods, and even the neutron source position can be changed by instructor or students. Fundamental characteristics of the Model 9000, such as neutron distribution, scattering, reflection coefficients, and neutron multiplication are nearly identical in nature with those in a full scale power or research reactor. The student may therefore become intimately acquainted with the fundamentals of reactor theory and design and may see for himself the effect on these characteristics of a change in the basic uranium configuration, amount of moderator, etc. Use of water as the moderator allows placement of foils, detectors, or neutron absorbers at any point within the lattice and greatly increases student interest.

Traversing mechanism is fitted to permit continuous automatic recording of vertical or horizontal neutron flux distribution within the uranium lattice, detection equipment being held in a vertical position by this mechanism. Two motors and two worm-gears provide the horizontal and vertical movements. A vertical traverse can be either up or down and may be started at any point between the grid plate on the bottom and the very top of the lattice. Maximum vertical movement is 40 in. A horizontal traverse also can be started at any point in any open radius—from the very edge of the tank to the neutron source tube in the exact centre of the lattice. Maximum horizontal movement is 24 in. to the source tube.

Registers attached to the two motors indicate the exact position of the detector at all times in inches and hundredths of inches. Speed of either traverse is 1 in. travel/min. Automatic variable stops are provided. The complete unit easily is attached or removed from the reactor.

Topside view of interior of Model 9000 reactor

N-Energy Developments In . . . . .

In this, the last article in his series on developments throughout the world, J. BURKETT makes brief reference to some of the countries not previously covered.

S. E. EUROPE

IN each of the more distant countries of Europe, active participation in nuclear energy developments is becoming apparent, and with the exception of Greece, technical assistance is being given by the U.S.S.R.

In Hungary, a 2 MW swimming pool research reactor has been built at the Nuclear Research Institute of the Hungarian Academy of Science at Debrecen, whilst similar reactors are planned for Bulgaria, with operation scheduled by 1960, and Rumania. The latter country has considerable reserves of hydro potential and lignite, therefore it is unlikely that the advent of nuclear power will come much before 1975, by which time there may be 500 MW of nuclear generating capacity. The Boris Kidric Institute of Nuclear Sciences in Belgrade already has a zero energy natural uranium heavy water facility. This went out of control in October, 1958, primarily, it is stated, through having insufficient qualified staff. In addition, Yugoslavia is having a 7-10 MW(heat) heavy water research reactor which was scheduled to go critical by the end of 1958.

Greek effort is being aided by the United States of America. Not only has a grant of $127,000 been given towards the cost of a nuclear engineering laboratory but also $350,000 towards the cost of providing Athens University with a 1 MW swimming pool research reactor. AMF Atomics are manufacturing and assembling the reactor whilst the fuel elements are being fabricated by Babcock and Wilcox. It was due to go critical at the end of 1958. Turkey is to have a research reactor sited near Ankara.

Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1975—Le role de L'energie nucléaire dans le'bilan énergétigue en perspective.

ISRAEL

IN spite of its small size and extremely limited resources, Israel's economy has been expanding rapidly over the last ten years, population having increased by nearly 100 per cent. The present generating capacity of 300 MW is expected to double by 1965 and by 1975 will probably reach 900 MW. The primary heavy power user is water pumping for irrigation. It is responsible for over 20 per cent. of the total output, a proportion that is likely to increase to 35 per cent. within the next decade when all available fresh water resources are expected to be in use.

There is little or no undeveloped hydro-electric power potential and very little brown coal, imported oil being the mainstay of electric power generation, production costs of which are over 8.5 mills/kWh. The introduction of nuclear power might be possible after 1965 provided reactors have been developed to give generating costs competitive with conventional stations at 8.5-10 mills/kWh. Dr. E. D. Bergmann, the head of Israel Atomic Energy Commission, stated recently that he believed the country will have its own power reactor by 1965.

In the meantime, nuclear research is being actively undertaken. The Weizmann Institute at Rehovoth now has a nuclear science establishment, the largest centre for research in the Middle East. Apart from a 3 MeV Van der Graaf accelerator, facilities will soon include a pool-type reactor that is being designed and installed by AMF Atomics. The U.S.A. is contributing $350,000 towards the cost. Uranium has been discovered in the phosphate deposits of the Negev and a heavy water process invented at the Weizmann Institute is being exploited in co-operation with France.

Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1616—A radioisotope training centre at Rehovoth, Israel.

TUNISIA

IN North Africa, Tunisia hopes to acquire a research reactor and a particle separator during 1959 and, in the next two years, a 10-15 MW reactor for the production of hot water or steam. Interest is being shown by the French national power utility, Electricité de France, in the introduction of a nuclear power station, possibly a boiling water type, at Fort Lamy in the Sahara.

Further south, in the Belgian Congo, it is understood that the University of Lovanium at Leopoldsville is to have a General Dynamics TRIGA research reactor. In South Africa, for the most part, early nuclear power is unlikely because of plentiful reserves of cheap coal. Areas like Cape Town and Port Elizabeth, however, are a considerable distance from the coal fields and fuel is more than four times the cost of that enjoyed elsewhere and it is here that the first nuclear power stations will be introduced. In isolated mining locations, such as the Tsumeb mines and the Consolidated Diamond Mines, there may be a requirement for small package reactors. Nuclear research so far has been on a small scale but it is possible that the Universities of Cape Town and Stellenbosch will collaborate in the establishment of an experimental reactor. As a first step, a Joint Committee for Nuclear Research has been formed.

U.A.R.

THE United Arab Republic appears to be preparing for active participation in nuclear energy developments. Egypt is receiving assistance from Russia in the construction of a 2 MW pool-type reactor near Cairo, whilst Syria has recently established an Atomic Commission. In Iran a 1 MW pool-type reactor has been bought from AMF Atomics for the University of Teheran.

NEW ZEALAND

SINCE 1954 electricity consumption has been rising at about 10 per cent. per annum, demand outrunning supply, resulting in voltage and power cuts, particularly in the North Island.

A 1957 official survey forecasted power shortage in the North Island by 1962 and in South Island by 1965 if there was no further expansion. Undeveloped sources of hydro-electric power were considered sufficient to meet future requirements for some years and it was unlikely that nuclear power would be applied before 1967. The following cost comparisons were primarily responsible for recommending extensive hydro developments: nuclear power, 1.0d./kWh (or more); hydro, 0.29d.-0.413d./kWh; geothermal, 0.362d.-0.470d./kWh; 180 MW coal-fired, 0.860d./kWh; costs being either of production at station or of delivery to sub-station.

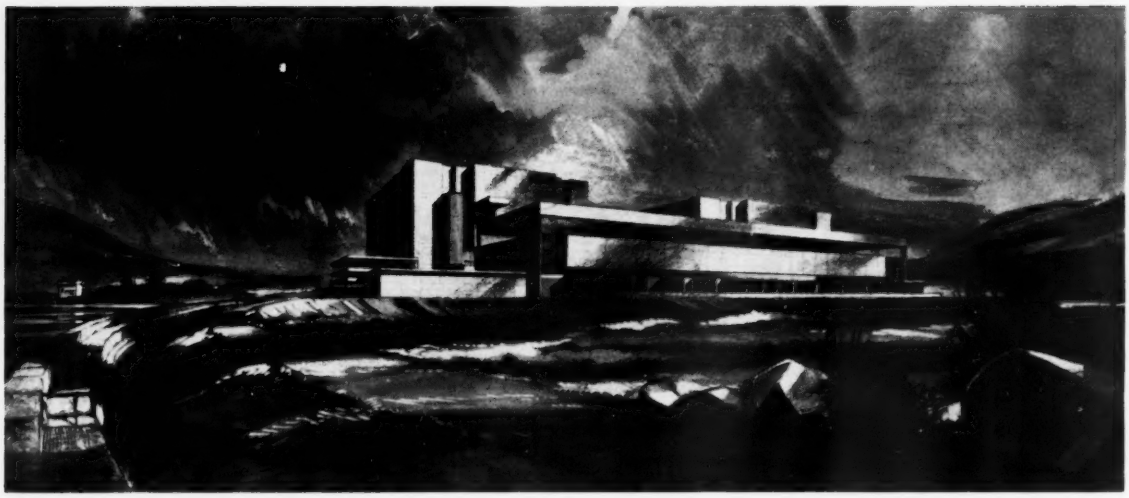
Nuclear research is in the care of the DSIR, through the Institute of Nuclear Science, set up in 1958.

AUSTRALIA

INDUSTRY is concentrated mainly on the eastern and south-eastern seaboards, in New South Wales and in Victoria with growing industrial development in Queensland, South Australia and Western Australia. This development is mainly dependent on easily accessible and adequate coal deposits. Apart from Tasmania where there is considerable hydro potential, the contribution that is likely to be made by hydro-electric power will provide a very small part of the power needs over the next 50 years.

In the coal-bearing areas nuclear power will only be able to compete at 4-5 mills/kWh. A stronger case exists in areas where coal supplies are distant and expensive. Mount Isa, in Queensland, for instance, an important mining centre for copper, lead, zinc and silver, is 600 miles from indigenous

(*Continued on page 422*)



Britain's FIFTH N-Station

WORK has started on the construction of the Trawsfynydd nuclear power station, which is to be built for the Central Electricity Generating Board by Atomic Power Constructions Ltd. The fifth nuclear power station to be built in Britain and the first in Wales, it will have two gas-cooled graphite-moderated reactors coupled to conventional turbo-generating plant with a net electrical output of 500 MW. The station is scheduled to come into operation in 1964.

DESIGN DATA OF APC'S STATION

Net electrical output	500 MW
Number of reactors	2
BOILERS	
Number per reactor	6
Height	116 ft
Diameter	18 ft
H.P. Steam	927 lb/sq.in. 715 F.
L.P. Steam	290 lb/sq.in. 685 F.
Heat rating	150 MW
REACTOR	
Pressure Vessel—	
Inside diameter ..	61 ft
Plate thickness ..	3½ in.
Operating pressure ..	240 lb/sq.in.
Core diameter ..	48 ft
Core height ..	27½ ft
GOLIATH CRANE	
Max. lifting load ..	400 tons
Span	250 ft
Height	200 ft

Atomic Power Constructions was formed at the end of 1956 and comprises Crompton Parkinson Ltd., Fairey Aviation Ltd., International Combustion (Holdings) Ltd., and Richardsons Westgarth & Co., Ltd., in association with Nuclear Civil Constructors. The last named firm comprises a partnership of Trollope & Colls Ltd., and Holland & Hannen and Cubitts Ltd., and will be responsible for the civil engineering part of the Trawsfynydd contract.

Crompton Parkinson will be responsible for the 275 kV generator transformers, station, unit and auxiliary transformers, the 11 kV, 750 MVA switchgear, 415v switchgear, switchgear control panels, auxiliary motors and alternators, cables and lighting equipment. Charge machines, control rod mechanisms and irradiated fuel disposal equipment will be supplied by Fairey Aviation, who will also be responsible for the machining and laying of the graphite.

The 12 boilers will be supplied by International Combustion, as will also be the main and recirculation CO_2 gas ducting and the biological shield cooling system. Richardsons Westgarth & Co., will be responsible for the 145 MW turbo-generator sets, the condensers and feed heating plant, dump condensing plant, and CO_2 gas circulators.

The two reactor pressure vessels will be built by Babcock & Wilcox Ltd., who are also to construct a 400 ton Goliath crane. Babcock & Wilcox are one of the companies engaged on the construction of the Hinkley Point station.

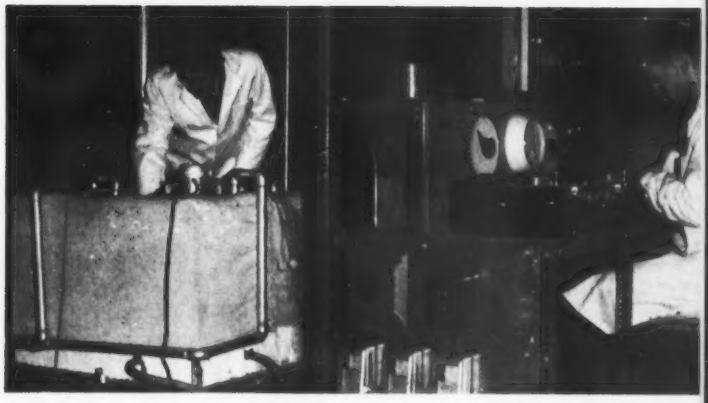
In addition to being responsible for the overall conception of the project, and for the design, supply, inspection, erection and commissioning of the complete station, Atomic Power Constructions will redevelop Portmadoc Harbour. About eight miles from the station site, this harbour will be used for the receiving of heavy plant and equipment sent by sea.

The site of the station is over 600 ft above sea level on the east face of Craig Gyfyns, Merionethshire, in the North Wales National Park. Levelling the undulating terrain will involve some 500,000 cu. yd of excavation, including a large amount of rock blasting. The site will be laid out in an economical terrace formation and because it is so exposed access passages between buildings will be covered.

Two years have gone into the design and development of the station, much of the research work involved having been undertaken at APC's laboratories at Heston. Station architect is Mr. Basil Spence, PRIBA, and the civil engineering consultants, Mott, Hay and Anderson.

RESEARCH BEHIND TRAWSFYNYDD

TO study various problems in reactor technology and develop techniques in reactor construction, Atomic Power Construction Ltd., have established at Heston, Middlesex, extensive research and development laboratories. Facilities are provided for investigation into the properties of all manner of materials and in testing their behaviour under simulated reactor conditions. It is important to know as much as possible about materials to be used in a reactor and in the fabrication techniques involved if the highest standards of safety and efficiency are to be achieved. An important part of the programme at Heston is devoted to an investigation into creep in steels used for constructing pressure vessels and boilers. Creep is the phenomenon by which steel may gradually change its physical dimensions under load. The rate of creep, which depends principally upon stress, temperature and composition, is very slow. To speed up the conditions under which it occurs and to acquire appropriate information a creep section containing a battery of creep machines has been set up. (A view of the 30 five ton machines in the main creep laboratory is shown above, the backs of these machines and their controls are shown in the illustration on the left). Creep is only one aspect of the study of reactor materials and steel only one of the materials studied. Research is carried out on uranium, for instance, and also on magnesium (illustration below shows low strain rate tensile testing machines for work on magnesium alloys)



(Above) *Vacuum-fusion gas analysis apparatus for the determination of oxygen, hydrogen and nitrogen in steels—one of the many pieces of apparatus in the metallurgical department of the APC Heston Laboratories.* (Right) *The wax model of a core, part of the neutron flux simulator* (extreme right) *in the reactor physics department*

HOPE that living standards in India would continue rising virtually for ever was expressed by Dr. Homi Jehangir Bhabha, FRS, Chairman of the Indian Atomic Energy Commission, when he was awarded recently the honorary degree of DSc at Cambridge University. Formerly a professor of physics at the Tata Institute, and now director of that same foundation, Dr. Bhabha was eminent even in the days when Lord Rutherford presided over the British Association meeting in India. In his Cambridge speech, Bhabha pointed out that more mineral resources have been consumed since the war than in the entire previous history of mankind. India and China can, in 25 years, become greater industrial powers than any European country, though living standards will still be low.

* * *

Sir Leonard Owen's outspoken assertion in Australia that Great Britain cannot afford to indulge in "paper reactors," but must develop systems which can generate power economically and on a large scale, adds point to the many misgivings that are felt about the British plans for nuclear-propelled ships. There are two reasons for building such ships. The first is that of prestige; the second is of a practical kind. Both reasons however can seriously be questioned. There is no doubt that enormous sums of money are spent these days just to "keep up with the Joneses," and this applies not only to the homely things such as the lawnmower, TV set, vacuum-cleaner, car, and washing-machine, but also to scientific pursuits. The Russians have their rockets and satellites, so have the Americans; now the British must have them also. For the same reason the French must have their H-bombs, and so, in turn, must Switzerland, Turkey, Ghana and Monaco in time.

* * *

The Suez crisis stirred up a lot of mud, and a whole lot of ideas. One of these ideas was that Britain *needs* large nuclear ships. These could maintain her prestige *and* serve a useful purpose too. If they were powered with American reactors, though, who will claim the kudos—we, or the Americans? The United Kingdom has sufficient engineering skill and talent to do the job, I am sure. The only trouble is that the American ship propulsion units are the only ones at present that have been shown to be feasible with practical experimentation.

On the question of practicability there is little doubt that if nuclear ships are to be really economical the whole approach to maritime transportation will have to be changed. There are already signs of this happening with, for instance, the industry's interest in cargo submarines. These would eliminate many of the problems associated with surface craft and also with the need for crews, as they would very likely be operated by remote control.

One problem to overcome would be that of speeding up turn-round at ports. This could be done by introducing pre-packaging of large sections of, if not complete, cargoes.

'NUCLEARIST' *writes . . .*

* * *

I recently visited Hinkley Point and Winfrith Heath. At Hinkley I was the guest of the English Electric-Babcock & Wilcox-Taylor Woodrow Atomic Power Group. On the Winfrith visit I was escorted by the UKAEA. The difference is not so subtle as it sounds. As a guest of the consortium I was provided with first-class travel, was breakfasted, lunched, wined and dined en route and treated as a guest of VIP proportions. In fact, had I lived within walking distance of Paddington Station I could have spent the whole day bleaching the linings of my pockets in the sun.

The trip to Winfrith looked much the same on the surface, but before I was able to be a guest I had to get there, after having paid my rail fare to a travel agency who sent me a bill which included "coffee and biscuits... 1s. 3d. *including gratuity*." The bill also told me that my dinner was to cost me 12s. 9d.... also including gratuity, of course.

Do I resent having to pay for my food, drink and transport? Of course not. The feeling of independence that goes into my wallet as every £1 note comes out is well worth the price. But I do object to public bodies resting complacently on the clichéd "public funds." We cannot entertain the press out of public funds, say the UKAEA, but they are very welcome. So is the publicity that results. The same applies equally to the Central Electricity Generating Board who had to rely on their employees, the contractors, to entertain the press to Hinkley Point.

I will probably be accused of displaying bad taste towards my hosts. In fact, the Editor has already frowned at me in a very dark fashion, but as he has given me the freedom of this column I intend to make full use of it.

Be assured that I want nothing for nothing. But as a taxpayer I see no reason why one public undertaking, i.e., the UKAEA or CEGB, should not make free use of the facilities provided by a fellow public utility, i.e., British Railways. The railway authorities are lavish hosts to the press when the occasion suits them. Why cannot their amenities be made available to a "colleague"? Or have they not been asked?

Book Review

Directory of Nuclear Reactors. Vol. 1. Power Reactors. Size 12 in. × 8 in. × 214 pp. Price 24s. Published by International Atomic Energy Agency.

This, the first major scientific publication of the Agency, gives details of 36 power reactor projects, 15 in the U.S.A., eight in the United Kingdom, four each in France and the U.S.S.R., and one each in Belgium, Canada, Czechoslovakia, Germany (Federal Republic) and Sweden. In some cases the projects involve more than reactor. The reactors have been grouped in six categories according to the coolant used—pressurized light water, boiling light water, heavy water, gas, organic fluid and liquid metal. Information is tabulated in such a manner to enable comparisons between different reactors to be made with ease. Details include not only mechanical and reactor physics data, but also names of designers and contractors, estimated costs and staff employed. A bibliography on each project is also given. There are many drawings illustrating reactor construction, fuel element design and coolant and steam flows.

NUCLEAR NEWS

- **200 MW Plant for Canada** *(This page)*
- **O.E.E.C. Radiation Measures** *(Page 420)*
- **DRAGON Meeting** *(Page 421)*

ATOMIC Energy of Canada, Ltd., is to begin immediately the final design and to plan the early construction of a large-scale nuclear power station. The plant is estimated to cost about $60m., exclusive of design and development costs, and could be completed and in operation late in 1964 or early 1965, at a site yet to be determined. Known as CANDU (Canadian Deuterium Uranium), the power station will produce 200 MW of electricity and will use a natural uranium-heavy water system. It will be similar in general principles of operation to the NPD (Nuclear Power Demonstration) atomic power station which is now under construction near Rolphton, Ontario, as a joint project of AECL, Ontario Hydro and Canadian General Electric Co., Ltd. The NPD station will produce 20,000 kW of electricity when it goes into operation in 1961.

I.A.E.A. Gift

A WIDE range of radiation measuring equipment and radiation sources, valued at $22,000, is to be supplied to Brazil by the International Atomic Energy Agency free of charge. The equipment is being provided as part of the technical assistance the Agency is giving Brazil in setting up a service to carry out precise measurement of radioactivity and radiation doses in connection with the purchase, distribution and use of radioactive materials. It will include radiation sources, ionization chambers of various types, Geiger counters, scintillation counters, radiation monitors and dosimeters. Countries from whom the Agency will buy the apparatus are Austria, Belgium, France, Germany, Norway, United Kingdom and the United States.

A New Exhibition

ENGINEERING materials and design, embracing virtually every industry in the world, is the subject of a unique exhibition to be held in London next year—the Engineering Materials & Design Exhibition. The first of its kind in the United Kingdom, it will be devoted solely to materials and components in engineering design. Organized by Industrial and Trade Fairs Ltd., it will be held at Earl's Court, February 22nd to 26th. Associated with the exhibition will be a conference for engineering designers held at the same time and in the same building. Lectures and papers will be presented from leading experts whose subjects will include ferrous metals and alloys, light metals and alloys, insulating and other electrical engineering materials, refractories, plastics, adhesives, powder metallurgy, rubber, inorganic materials, bearings, clutches, casting techniques, seals, drives, couplings, control techniques, appearance design.

Waste Consultants

W. J. FRASER & Co., Ltd., chemical engineering contractors of Romford, Essex, have been appointed by Eurochemic as consultants on the treatment, containment and disposal of all radio-active effluents from Eurochemic's processing plants and laboratories to be built at Mol, Belgium. The decision that Eurochemic should seek help from Britain with the problems of dealing safely and completely with such effluents has been taken because of the considerable British experience in this field. W. J. Fraser will be able to draw on advice from the UKAEA; it will be remembered that Frasers were recently awarded a contract by the UKAEA to design a plant to separate and recover radio-active fission products.

Analysis by Radiation

FIFTY-NINE scientists from 21 countries attended the three day symposium on radio-activation analysis recently held in Vienna. The meeting was arranged by the International Atomic Energy Agency and the Joint Commission on Applied Radioactivity of the International Council of Scientific Unions. It provided the first major occasion for a full consideration of the techniques and practical aspects of activation analysis, which is a relatively new method of analyzing constituents of a material making it radioactive.

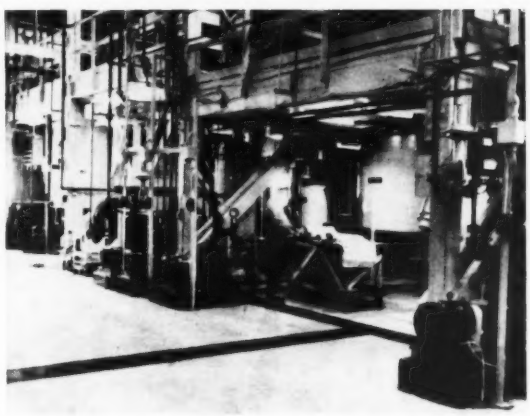
Oil Monitors

THE Iraq Petroleum Co., Ltd., have ordered nine of the recently developed Ekco Type N611 nucleonic fluid density gauges for monitoring their oil pipelines in Iraq, Syria and Lebanon. This pipe runs 555 miles mostly across desert from Kirkuk to Tripoli. Different grades of oil are obtained from the main distribution centre at Kirkuk and are pumped successively along a common pipeline. At Tripoli the different grades of oil are segregated and for this reason it is essential to know the location of the interface between the different oils on arrival. Ekco gauges are being installed at the initial switching position at Kirkuk, at the terminal switching position at Tripoli and at three intermediate pumping stations along the line. Each of the gauge installations comprises a measuring head, an indicator unit, a recorder and an audible alarm unit. The principle of operation of the Ekco fluid density gauge depends upon the passage of gamma rays through the pipe walls and the extent to which their passage is impeded by the fluid contained between the pipe walls. By this means, density variations as low as .002 s.g. can be detected without access to the fluid concerned. There is no danger from radiation because the radio-active source used is housed within a shielded container fitted with a safety shutter.

Nuclear Finance Cut

ITALY'S National Committee for Nuclear Research has had its financial allocation from the Government for the current year cut by half to £3m.

Canada's First Thorium Plant



A section of the $1m. thorium plant built by Humphreys & Glasgow (Canada), Ltd., for Rio Tinto Dow, Ltd. Shown are mixing and surge tanks. The plant, which is almost fully automatic, is designed for an annual output of about 150 tons of thorium. The plant building is constructed entirely of timber

Under-18-year-old Ban

THE 17 countries of the Organization for European Economic Co-operation have agreed on common measures towards safeguarding their populations from the dangers of nuclear radiations. The OEEC Council has adopted a decision requiring member countries to ensure adequate health protection for all persons who might be exposed, whether occupationally or otherwise, to ionizing radiations. Appropriate safeguard measures to meet emergencies or accidents involving these radiations must also be taken. Finally, all countries are called upon to report to the European Nuclear Energy Agency, by November 15th, on their legal and administrative measures in this field, so that the Agency can make a comprehensive survey by the end of the year. The Council further recommended that the health protection measures called for should be based on common norms which have been developed by an international group set up in May 1958 by the European Nuclear Energy Agency under the chairmanship of Dr. Mogens Faber, of Denmark. Collaboration within this group between leading radiation experts in the OEEC countries and Euratom has enabled uniform measures to be recommended for all European countries. These norms are themselves based on the recently revised recommendations of the International Commission on Radiological Protection (ICRP). There are three categories of application for the norms:—(i) to occupational exposure in "controlled areas" (defined as areas containing a source of ionizing radiation where persons occupationally exposed could receive doses in excess of 1.5 rems/year); (ii) to "surveyed areas" (defined as areas in the vicinity of controlled areas, where residents may be exposed to radiation from the controlled areas); and (iii) to any other areas, that is, the population as a whole. For each of these categories, the norms give formulae and tables defining recommended maximum permissible doses. These doses range from 5 rems/head for the general population, accumulated over 30 years—to a maximum of 3 rems/head, distributed over 13 consecutive weeks, for persons over the age of 18 working in "controlled areas," provided that the average yearly dose accumulated does not exceed 5 rems. No person under 18 may be engaged in any activity in which he might be occupationally exposed to the hazards of ionizing radiations. The norms cover methods of "accounting," in cases where accidental exposures may have taken place, in order to ensure protection against excess accumulated doses. They also set out recommendations for personnel radiation monitoring, medical examination, surveillance and control in "controlled areas."

N-Material Accounting

REGULATIONS covering the accounting of nuclear materials by member countries of EURATOM have been published. They appear in the May 29th, 1959, issue of the Community's *Journal Officiel*. They specify the nature the information which must be regularly communicated to EURATOM to enable an account to be kept of quantities and locations within the EURATOM area of uranium and thorium ores and the raw and fissile materials derived from them. Details of transfer between countries will also have to be made known. Countries will be free to devise their own internal accounting systems.

Hunterston TV

THE first part of a large order for closed circuit television equipment to be supplied to the Hunterston nuclear power station has been placed with Pye Ltd. The television is to be used for observation inside the reactor and for the monitoring of various other services. The contract, which involves the supply of about 30 special-purpose TV cameras of various designs, is worth about £50,000.

Nuclear Meeting

OVER 1,100 nuclear scientists, 65 American organizations and three foreign governments took an active part in the recently held American Nuclear Society national meeting at Gatlinburg, Tennessee. More than 200 technical papers were presented to the meeting and among the subjects they dealt with were the recent criticality accidents at Oak Ridge and Los Alamos, fast reactor safety latest developments in the processing of irradiated fuels, how neutron age affects safety and design considerations, and the work the Society is doing to establish standards for safe reactor design, safe reactor location, safe handling of fissionable materials outside reactors, safe operating standards, and the principles of safety systems.

People in the N-News

A DIRECTOR of the nuclear laboratories being built by the Central Electricity Generating Board at Berkeley, Gloucestershire, has been appointed. He is **DR. C. P. HAIGH,** BSc, PhD, FInstP. Thirty-nine years old, Dr. Haigh read physics and electrical engineering at Leeds University graduating with honours in 1941. He then conducted nuclear physics research at London University for which he was awarded a PhD degree. For two years he was assistant physicist at the Ferranti electronics laboratory at Hollinwood, Lancs., and then until 1949 was physicist at the research laboratories of Thorium Ltd., at Amersham, Bucks. While he was

Dr. C. P. Haigh

there the laboratories became the Radiochemical Centre. From 1949 to 1956 Dr. Haigh was principal physicist at Barrow Hospital, Bristol. He then joined the CEGB as head of their nuclear physics section.

MR. D. H. HILL, of the U.K. Atomic Energy Authority, has been appointed Resident Nuclear Energy Attaché to Mr. A. H. Tandy, the U.K. Government's representative to the European Atomic Energy Community (EURATOM) in Brussels. H.M. Government appointed a permanent representative to EURATOM last year. The agreement between H.M. Government and EURATOM, which was signed in London in February, provides for close collaboration between the parties for the promotion and development of the peaceful uses of nuclear energy. The Nuclear Attaché will act as adviser to the U.K. representative and will keep in touch with nuclear developments in all the six member countries of EURATOM. Mr. Hill, who is 40, is a chemist. He has been a member of the staff of the Authority's industrial group since 1956.

AN eight man team from the International Atomic Energy Agency is visiting Latin America in response from Argentina, Brazil and Venezuela for advice on the development of various aspects of their nuclear energy programmes. Argentina is particularly interested in advice on the prospecting of uranium ores and their mining and processing. Venezuela wishes to develop a research programme in connection with its research reactor and also wishes to consult Agency experts on the establishment of an atomic energy commission. Brazil has indicated her interest in advice on all aspects of its expanding nuclear programme. Leader of the Mission is **MR. EDWARD R. TRAPNELL,** special assistant to the IAEA director-general. Mr Trapnell has more than 13 years' experience in nuclear energy having worked with the U.S. Atomic Energy Commission, in the American nuclear industry and with the International Agency. Other members of the mission are **MR. A. GERSTNER,** acting chief of the research division of Vendee of the French Atomic Energy Commission's Mining and Research Department; **DR. RUDOLF HOFER,** head of the radioisotope laboratory at the Second Medical University Clinic, Vienna; **MR. D. G. MAXWELL,** consultant metallurgist to the General Mining and Finance Corporation of Johannesburg; **MR. A. C. SCHUFFELEN,** of the Soils and Fertilizers Laboratory, University of Agriculture, Wageningen, Holland; **MR. JOAQUIN CATALA,** of IAEA's Division of Exchange and Training, previously dean of the Science Faculty, Valencia University, Spain; **MR. S. K. DHAR,** IAEA Division of Economics and Technical Assistance; and **MR. VLADIMIR SHMELEV,** member of IAEA's reactor division, previously with the Moscow nuclear power station.

I.A.E.A. Talks Ahead

A MAJOR international conference will begin in Warsaw on September 8th, to discuss the application of large radiation sources in industry, particularly to industrial chemical processes. The conference, which is being organized by the International Atomic Energy Agency, will last five days and is expected to be attended by more than 200 delegates from all parts of the world, representing different branches of industry, technology and scientific research. This will be the first major scientific conference to be held by the Agency to promote the peaceful applications of nuclear radiation.

DRAGON Meeting

AT the first meeting of the International Board of Management of the OEEC High Temperature Reactor Project (DRAGON), held to-day at the Atomic Energy Establishment Winfrith, Dorset, where the reactor experiment is to be built, Dr. Sigvard Eklund, of Sweden, was elected chairman of the board for the current year, with Sir John Cockcroft, of the United Kingdom, as vice-chairman (Sir John has since been succeeded in this position by Sir William Penney). The board appointed Mr. C. A. Rennie, of the AERE, Harwell, as chief executive of the project. A number of nominations were received including some from continental participants, for other senior posts. The board considered and approved a broad programme of work and a budget for the financial year, 1959-60, on the basis of preparatory work by a general purposes committee under the chairmanship of Dr. J. Gueron (EURATOM).

For the Swedes

HEAT transfer tests of fuel element bundles are being carried out for Aktiebolaget Atomenergi, of Stockholm, by the Hawker Siddeley Nuclear Power Co., at their Langley, Bucks, laboratories. The company are using a heat transfer rig which provides for pressures up to 600 lb/sq.in. gauge and temperatures up to 450°C. The tests are in connection with Swedish investigations of heavy water gas cooled reactors.

Bristol Channel Scene

The 3,900-ton cooling water intake caisson for Hinkley Point (Somerset) nuclear power station being towed into position 2,000 ft offshore. When the station is in full operation in 1962 water will pass through this caisson at the rate of 35m. gal/hr to be fed via 12 ft diameter tunnels into the station. In the background can be seen the two reactor buildings and the 400-ton Goliath crane. The station is being built by the English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Group

U.S. Firm's Europe Plant

HIGH Voltage Engineering Corporation, of Burlington, Mass., manufacturers of radiation-producing particle accelerators, are planning to establish a manufacturing plant in Amersfoort, Holland. Mr. Denis M. Robinson, company president, has said that High Voltage, who are the world's principal suppliers of Van de Graaf and electron linear accelerators for nuclear physics research, electron beam processing, supervoltage X-ray therapy and industrial radiography, intend to enter directly into the European Community, offering European-made equipment, as well as local service and sales, to European countries. Already, the company has installed more than 200 machines in the world since starting operations in 1946. Thirty-seven particle accelerators are now installed or on order in Europe, 18 of them in the Common Market. Sales have been carried out directly from Burlington, Mass., with the assistance of distributors in several overseas locations. "Key distributors will be retained," says the president, "and will be supported by sales effort from both the Netherlands and from the United States."

NUCLEAR NEWS

Talks at Riso

A THREE day symposium on technical methods in health physics recently held at the Riso Research Establishment of the Danish Atomic Energy Commission was attended by 120 scientists. They discussed the scientific and technical aspects of health protection for personnel in nuclear installations and laboratories and made comparisons between experiences in their own laboratories and installations. Proceedings of the symposium, which was organized by the OEEC Nuclear Energy Agency in conjunction with the Danish AEC, are to be made available for wide distribution.

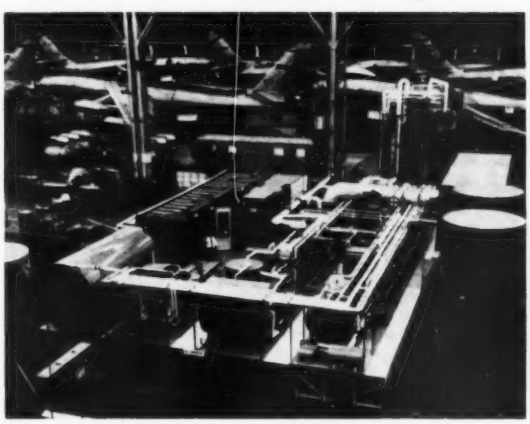
For a New Lab

THE United States are to contribute $600,000 for the International Atomic Energy Agency's functional laboratory to be built at Seibersdorf, near Vienna. Holland is to supply a gamma spectrometer.

Welding Talk

THE second annual lecture of the Institute of Welding was recently given by Sir Leonard Owen, CBE, managing director of the UKAEA Industrial Group. His subject was "Welding and the Nuclear Power Programme."

Reactor by Air



A full-scale mock-up of the portable nuclear reactor plant designed by Lockheed Aircraft. The entire plant can be crated and shipped aboard 16 air freighters to any point in the world in one and a half days. Output of the plant is given as 1,000 kW of electricity. It would be fuelled with enriched uranium

Canada's New Tandem

A NEW 10m. volt tandem accelerator has gone into operation at the Chalk River plant of Atomic Energy of Canada, Ltd. Built by High Voltage Engineering Corporation of Burlington, Massachusetts, it consists of two van der Graaf accelerators placed end to end horizontally in a 23-ton steel pressure tank, 34 ft long and 8 ft in diameter. The tank contains nitrogen at a pressure of 225 lb/sq.in. to prevent the escape of the electrical charge built up by the machine. A beam of particles is directed from the first of the two van der Graaf units where it is given an energy of 5m. volts into the second unit, where the energy is boosted to 10m. volts. Cost of the accelerator is $1m.

The Stresa Congress

GOVERNMENT officials and representatives of industry from 15 countries, including Britain and the United States, attended the four-day congress organized by OEEC at Stresa at which industrial prospects of nuclear energy were discussed. In the sessions on the economics of nuclear energy a number of speakers expressed the hope that the conference might mark the beginning of a determined attempt by the European and American countries to assess the economic implications of nuclear development. The European countries in which the greatest investments were being made were Britain and France. In Britain yearly investments in the order of £100m. each were made by the Atomic Energy Authority and by the Electricity Authority, and another £15m. was contributed by private industrial syndicates. In France the investments were in the order of 100,000m. francs (£72m.) a year. The magnitude of these figures emphasized the importance of international co-operation. An example of such co-operation in the field of production of special fissile materials was Eurochemic, a joint venture by a number of OEEC countries. A plant for the chemical reprocessing of irradiated fuel and plutonium production was being built under the scheme at Mol, in Belgium. The main problem was that of costs. It was generally recognized that at present the traditional sources of electric power were cheaper, but confidence was expressed that if a determined effort were made to investigate the possibilities of bringing costs down by understanding their component factors, nuclear energy as a source of electricity power could become competitive in five years' time. On costs, the German delegate, Dr. Lobl, said that at the moment the gas-cooled graphite moderated type and the light water type of reactors were the most expensive, while in theory the organic moderated type was the cheapest. This, however, had not yet been proved by experience.

Efficiency Progress

LAST year, a reduction in fuel cost, equivalent to just over £4½m., resulted from the improved thermal efficiency of the power stations operated by the Central Electricity Generating Board. The overall average thermal efficiency during the 12 months of 1958 was 25.99 per cent. as compared with 25.38 per cent. for the previous year. Over one-third of the 84,670m. units supplied from these stations in 1958 was provided by the 20 most efficient stations, which had an average efficiency of 30.23 per cent.

For the A.G.R.

W. H. ALLEN, Sons & Co., Ltd., have announced that they are to supply two diesel engine-driven generator sets to provide standby supply to essential services for the AGR at Windscale. The plant consists of two 12-cylinder, vee-form, pressure-charged, Allen type VBS12 engines, each running at 600 rev/min and driving a 600 kW, 240v Allen d.c. generator.

NUCLEAR NEWS

Equipment for Latina

AN order has recently been placed with the Dryer and Gas Plant Division of Birlec Ltd., for two dryers to be supplied for the Italian nuclear power station under erection at Latina. To be installed in the main reactor cooling circuits, the dryers will remove water vapour from the carbon dioxide gas used in the heat transfer system. This order brings to a total of 18 the number of carbon dioxide dryers being supplied by Birlec Ltd., for nuclear stations at Latina, Berkeley, Bradwell and Hunterston. Birlec has also supplied the air dryer installed at Dounreay in the fast breeder reactor vessel.

European Plants

FIVE firms—from Belgium, France, Germany, Italy and the Netherlands—are to submit proposals for power reactors to be built by 1963 under the common United States EURATOM nuclear power programme. The main feature of this programme is the building of power stations in the six EURATOM countries with a total installed capacity of 1,000 MW. The proposals will be submitted during the Autumn.

To Speed Sub Research

NUCLEAR propelled submarines may be the hottest thing in the marine world to-day, but the men who build them are calling in an ordinary steam boiler to help speed up construction testing of America's undersea fleet. The boiler, scheduled to be put into use later this year, will be mounted on a barge which will be towed to submarine construction piers within General Dynamics Corporation's electric boat division's yard along the Thames River in Groton, Conn. Steam from the unit will be used to test various steam plant components of the secondary system in the nuclear submarine. According to officials of the Babcock & Wilcox Co.'s Boston sales office, which contracted with the electric boat division to supply the boiler, the test unit is expected to reduce the time required to turn out nuclear submarines. Just prior to the installation of the reactor in the submarine, the boiler will be used for a complete " shake down " of the secondary, or steam, plant. For testing, the unit will be hooked up to the submarine by flexible steam connections. The new boiler, which will be available for operation on short notice, is expected to accelerate the testing procedure, making possible substantial savings.

N-Developments in Australia

(*Continued from page 415*)

supplies. In the extreme north of Australia there are large deposits of bauxite and, with cheap nuclear power, a major aluminium industry is possible.

In highly industrialized South Australia coal reserves will soon be fully committed to the new power stations under construction. Further expansion will be dependent upon either imported coal or oil, or on nuclear power. There are remote locations where 5-30 MW nuclear power plants might be of promise provided that capital costs were not excessive and skilled supervision was as low as possible. Reactors for the economic purification of saline water would enable vast undeveloped areas to be opened up.

Nuclear power developments are the responsibility of the Australian Atomic Energy Commission which was formed in 1953. Its aims are to encourage and assist private enterprise in the search for uranium and to collaborate with State government agencies; to supervise the overall development of the uranium works at Rum Jungle, Radium Hill in South Australia and Mary Kathleen field; establishing a research programme and a reactor facility; and a radioisotope service.

The Commission's research establishment at Lucas Heights near Sydney was officially opened on April 18th, 1958. Its first research reactor HIFAR (Dido type) which went into operation last year has some 50 irradiation facilities. As only one reactor has been planned for the preliminary phase of the research programme, a wide range of experimental facilities have been incorporated. The provision of a high flux reactor together with experimental laboratories is a step towards the long-term study of high temperature systems. An extensive programme of work has been planned in exploring the uses of beryllium and beryllia in these systems. Another system to be investigated is the liquid metal reactor using sodium slurry as a coolant and fuel carrier with beryllium as moderator. Loop tests relating to both the high temperature and liquid metal system will be carried out in HIFAR.

In order to provide for university research and training the Atomic Energy Commission in conjunction with the Universities have jointly financed an Institute of Nuclear Science and Engineering.

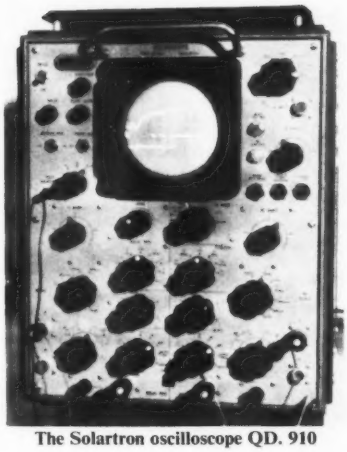
Further details can be obtained from the following paper presented at the 2nd International Conference on the Peaceful Uses of Atomic Energy:—P/1093—Design and construction of research facilities for a power developn ent programme.

Equipment and Materials

Items published in this monthly feature are compiled from manufacturers' current literature. Readers requiring further information should use the form at bottom of the page. Manufacturers are invited to send literature or details of their products for inclusion in this feature.

Persistent Oscilloscope

To arrest transient phenomena and be able to study it at leisure by a trouble-free method has long been a need of scientists and engineers in almost every field of scientific research, development and industry. The new Solartron infinite persistence oscilloscope, type QD.910, enables this to be done by freezing non-recurrent waveforms and other types of curves on an oscilloscope screen for as long as may be desired. It employs a "Memotron" storage cathode-ray tube which gives an infinite trace persistence. The trace is immediately erasable after each investigation is completed. The QD.910 is a dual-channel instrument, each channel having a bandwidth of d.c. to 1 Mc.p.s. The instrument has several special facilities. It has provision for external brilliance ("Z") modulation of the time base waveforms and delay pulses are brought out on the front panel. An internally-generated waveform provides automatic erasing for initial setting of the tube controls, such as focus, shift, etc. The "sampling" mode of operation is extremely important. In this, the time-base makes one stroke, and the resultant trace is stored for any period up to 100 sec. The trace is then automatically erased and this sequence repeated continuously. This mode of operation is particularly useful for locating a particular piece of information stored, for example, on magnetic tape. The writing-gun current is automatically adjusted according to the velocity of the spot to produce storage at high writing speeds without excessive beam current at low writing speeds. This ensures a uniform picture brilliance for all types of work. The "Memotron" tube contains an orthodox "writing" gun and deflector plate assembly with an acceleration potential of 3 kV and a medium persistence viewing screen with a potential of +3 kV applied to it. Behind the viewing screen are two fine wire meshes which are the collector and storing meshes. The first, which is adjacent to the viewing screen, has a coating on the far side of a dielectric material, which has a secondary-emission coefficient, and is normally at zero potential. The collector mesh is set at +160v. A second gun, the flood gun, is mounted to the side of the deflector plates and floods the screen of the tube with slow electrons. When the writing gun is cut off flood electrons leak through the storage mesh and are attracted to the viewing screen where they produce a dull uniform illumination of the screen. When the writing gun is turned on and deflector voltages are applied to the plates of the tube, the fast moving electrons from the gun strike the storage mesh and produce secondary electrons from the dielectric coating. The area thus written upon loses more secondary electrons than it gains primary ones, thus making positive charges which attract flood electrons which in turn pass through the mesh and are attracted to the highly positive viewing screen reproducing on it the pattern on the mesh. The flood gun maintains the positive charge on the storage mesh indefinitely. Once a given area has risen above a certain potential level, it accelerates the flood electrons sufficiently to release further secondary electrons, and thus its potential continues to rise until it approaches that of the collector mesh, at which potential it stabilizes. Thus the positive charge pattern is maintained. **(AU 1).**



The Solartron oscilloscope QD. 910

New Heat Recorder

After extensive field trials on the plant of some of Britain's largest instrument users, Fielden Electronics Ltd., recently announced their new transistorized four point temperature recorder. This has a 10 in. diameter chart and operates from the normal 50 cycles mains supply. Resistance bulbs are used as the temperature sensitive elements and low range spans are easily achieved. The use of transistors has significantly reduced the power dissipated in the instrument and has resulted in improved performance and greater reliability. Particular features are the new improved stability control and the very high reproducibility. **(AU 2).**

Fielden's transistorized temperature recorder

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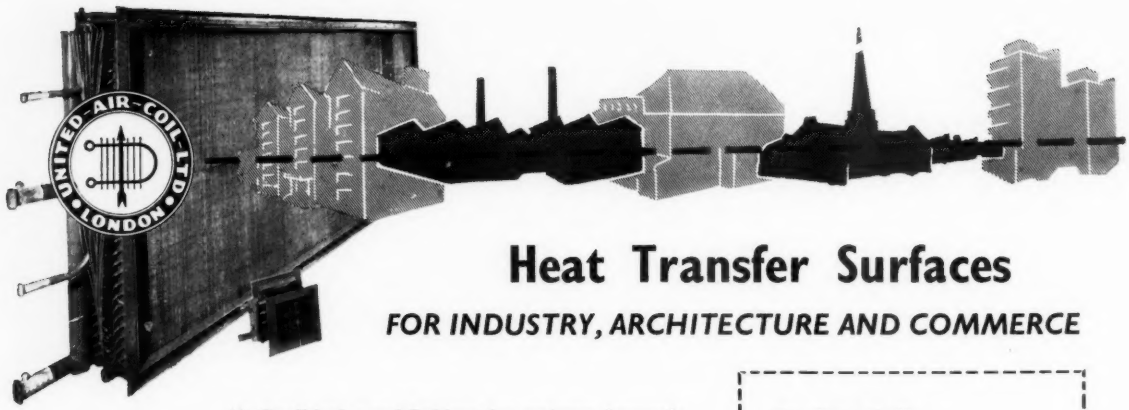

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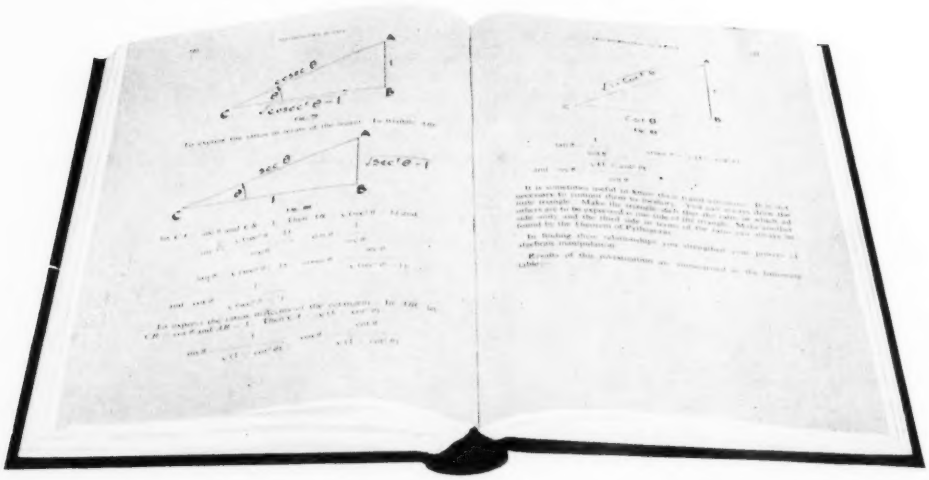

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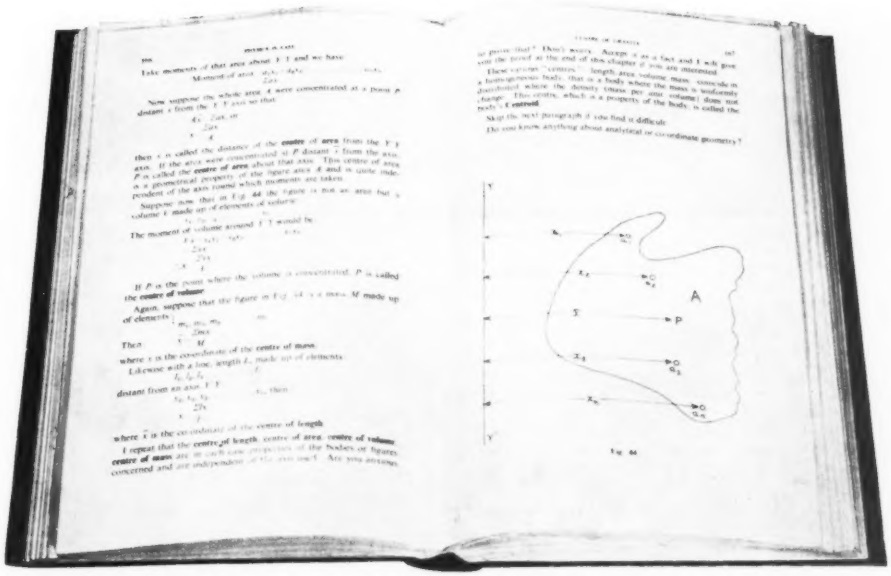

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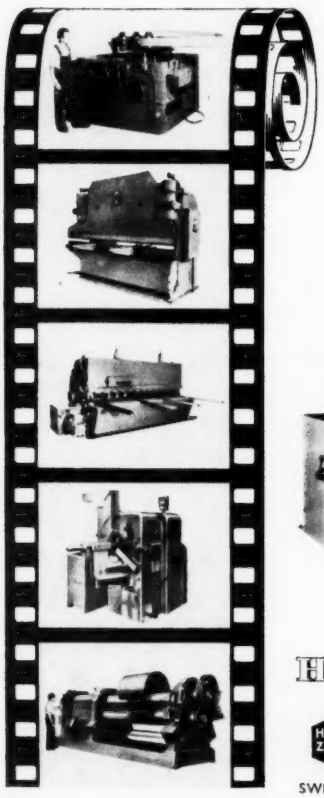

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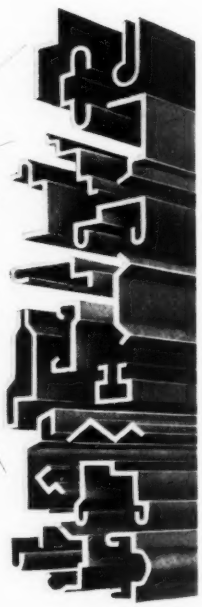

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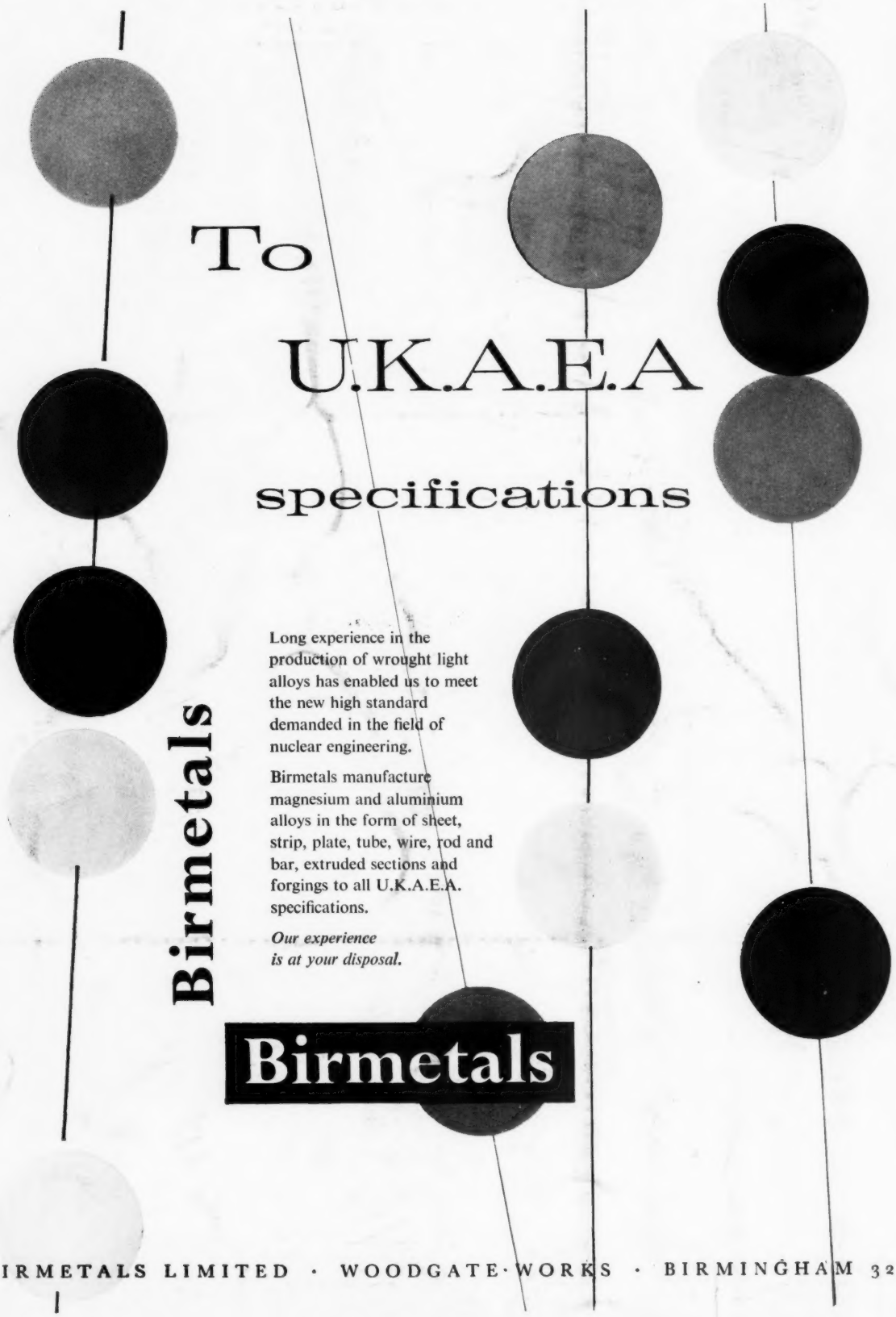

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